Volume 13 JUNE 1929 Number 6

BULLETIN
of the
American Association *of* Petroleum Geologists

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THE BULLETIN

of the

AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS

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BULLETIN

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AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS

JUNE 1929

HISTORY OF THE CARBONIFEROUS SEDIMENTS OF THE MID-CONTINENT OIL FIELD[1]

M. G. CHENEY[2]
Coleman, Texas

ABSTRACT

Obviously, the study of successive controlling geologic conditions and influences has many direct applications to the problems of the oil geologist with his duties of interpretation and prediction.

The Carboniferous sediments of the Mid-Continent region were deposited upon a basement which was exceedingly well base-leveled but very complex structurally due to 10,000 feet of structural change during earlier Paleozoic, and far greater changes during pre-Cambrian times. Accumulation occurred mainly in shallow seas, hence practically at sea-level and without appreciable regional dip. Great inequalities in thickness required extensive structural changes within the basin areas, and the arrival of vast quantities of coarse material indicates equally extensive and concurrent uplift of areas around the basins. Such interrelation of negative and positive movements furnishes the basis for certain important deductions.

Six successive groups of sediments are discussed as to character, location, thickness, and probable source. The oscillatory and migratory tendencies of these basins are noted and attendant structural effects discussed.

Analysis of the various types of structure of this region is attempted, and maps are submitted showing net results of structural changes since (1) early Pennsylvanian and (2) Jurassic times.

It is concluded that unequal subsidence and diastrophism caused by subcrustal pressures associated with successive basin subsidences best explain the ordinary oil-field type of structure and the successive rejuvenations. The Ouachita geosyncline and synclinorium are considered the dominant features of the region, and a diagram is included indicating the successive developments in this area of greatest deposition, structural change, and erosion.

INTRODUCTION

The very extensive group of sediments which are the subject of this discussion exhibit evidence of great differences of origin and of having endured many diverse influences following their deposition. As geologic

[1]Read before the Association at the Tulsa meeting, March 26, 1927. Manuscript received by the editor, March 7, 1929.

[2]President, Anzac Oil Corporation.

effects are cumulative and each earlier condition is included in the present sum, the correct interpretation of features now observable will depend to a large degree upon acquaintance with the entire history of the beds being studied. To illustrate this it may be cited that when analysis is made of the successive positions of the Bend group of north-central Texas, as may easily be done by study of thickness of subsequent deposits, it seems certain that the supposed arched uplift was formed by westward tilting (mainly during the Permian) of eastward-dipping monoclines which developed during Strawn time (east-southeast in early Strawn, followed by more gentle northeast tilting during later Strawn, shown in Figures 2, 3, and 4). The term "Bend flexure" is urged in lieu of "Bend arch" as a preventive of erroneous deductions based on a supposed great regional uplift which never occurred.

Observations in the Mid-Continent oil field force the conclusion that in regions of moderate folding the structural conditions present or formed soon after deposition of petroliferous beds have controlled (in so far as porosity permits) the main migration and accumulations of oil. This seems logical, for the period of accumulating overburden witnesses the development of the most effective force and affords the most favorable conditions for the migration of fluid petroleum substances in these lenticular, transitional sediments. When compacting of the compressible members by increasing overburden ceases, fluid movements through these discontinuous beds must be very limited. On the other hand an overburden of 1,000 feet makes available pressures of about 1,000 pounds per square inch, or more than twice the normal hydrostatic pressures of the fluid column being continuously expelled during compaction. The expelled fluid volume must be nearly equal to the reduction in pore space in the compressible beds, which, according to Hedberg's[1] data, means that each acre foot of saturated mud will yield during burial fluid volumes approaching the following:

Thickness of Overburden	*Per Cent Porosity of Compacting Mud*	*Per Cent of Original Volume Lost*	*Approximate Volume of Fluids Lost per Original 43,560 Cubic Feet*
50	50.0	....	.....
1,000	30.0	28.6	12,450
2,000	23.0	35.1	15,280
3,000	18.0	39.1	17,030
4,000	14.7	41.4	18,030
5,000	12.2	43.1	18,750

[1] H. D. Hedberg, "The Effect of Gravitational Compaction on the Structure of Sedimentary Rocks," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 10 (1926), pp. 1035-72.

Thus fluid movements during the first 1,000 feet of burial appear to be twice as much as during an additional 4,000 feet of accumulation. Beckstrom and Van Tuyl[1] have demonstrated experimentally the effectiveness of compaction in causing the migration of oil from a shale-water-oil mixture, their conclusion being "that compaction is by far the most important cause of the migration of oil from shales into porous reservoirs."

Reeves[2] has emphasized the widespread verification and general acceptance of Hilt's law, that the degree of carbonization increases with the stratigraphic depth in a series of similar coals. He found that for the Appalachian oil field, 145 feet of additional stratigraphic depth gives the same increase in carbon-ratio as does 10 miles approach toward the area of great orogenic movement, indicating that lateral pressures in the sediments in such areas are negligible compared with pressures from overburden.

The nature of the beds and of the organisms and organic material (decaying under anaerobic conditions) commonly held to be the sources of petroleum gives assurance that oil is present in some fluid form in compressible beds during this early period of rapid expulsion. No doubt these escaping fluids migrate toward and through the most accessible incompressible large-pored beds or voids and onward toward areas of least pressures, that is, structurally high and marginal areas, these being the areas of least overburden. On this basis the northward thickening of beds overlying the Woodbine sands may possibly explain the scarcity of oil in these sands north of Navarro County, Texas.

Accumulation of oil should occur along favored trends where further migration is impeded by local structural "highs" or by marked reduction of pore space or pore diameters from any cause. Having reached a protecting incompressible haven, the further movement of oil in a series of nearly flat lenticular beds must be most improbable, for water would commonly prevent migration of oil into lower structural positions or into rocks of very fine pores. It is firmly believed that much help in the search for oil may be derived from preparing both regional and local isopach maps of a definite group of beds overlying an oil-bearing horizon, this being the logical means of deciphering the early structural features which largely controlled fluid movements during the period of most ac-

[1] R. C. Beckstrom and F. M. Van Tuyl, "Compaction as a Cause of the Migration of Petroleum," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 12 (1928), pp. 1049-55.

[2] Frank Reeves, "The Carbon-Ratio Theory in the Light of Hilt's Law," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 12 (1926), pp. 795-823.

tive migration. The foregoing is intended to emphasize that an acquaintance with the entire history of sediments and structures is exceedingly important to the oil geologist.

PURPOSE

The main purpose of the writer is to review in succession the more important depositional and structural developments affecting the Mississippian, Pennsylvanian, and Permian sediments throughout the large region inundated by these ancient shallow epi-continental seas and known at present as Oklahoma, Texas, and adjoining states.

The possible benefits of such a study are unlimited, for this region displays a very great variety of sediments and structures, numerous detailed geologic reports are available, and the information to be derived is of a useful nature.

Many deductions which seem best to explain the conditions as they appear to the writer but which are necessarily more or less theoretical are included in the hope of developing discussions which will lead to a better understanding of things observed. The reader is expected to treat such deductions with the usual caution and to differentiate carefully between fact and theory.

RÉSUMÉ

Sederholm[1] has concluded from his extensive studies that the pre-Cambrian depositional (including glacial) and mountain-building processes differed little, if any, from those of subsequent times; that as great a thickness of sediments accumulated and as much time elapsed during the basin accumulations, the granite effusions, and the great periods of erosion of four pre-Cambrian systems as during all later eras; possibly even more time was required.

Leith[2] has recognized at least three periods of plutonic granite intrusion in the Lake Superior pre-Cambrian.

The Mid-Continent region may have experienced similarly extensive pre-Cambrian deposition, folding, effusions, and erosion. Thick beds of this age highly compressed along northwest-southeast axes are exposed in the Llano-Burnet region of central Texas. Well cuttings in western Missouri, in northeast and east-central Texas, and other parts

[1] J. J. Sederholm, Response, upon receiving Penrose Medal, Geological Society of America, December 28, 1928; Also "Pre-Cambrian of Fennoscandia," *Bull. Geol. Soc. Amer.*, Vol. 38 (1927), pp. 813-36.

[2] C. K. Leith, "Lake Superior Pre-Cambrian," *Bull. Geol. Soc. Amer.*, Vol. 38 (1927) pp. 749-52.

of the region have found varying thicknesses of schistose and gneissic material of these oldest basin deposits.

Additional profound structural changes occurred within this region from Cambrian to Devonian times inclusive, as a very deep sedimentary basin developed across southern Oklahoma. Doubtless the ordinarily accompanying, more or less parallel, structural irregularities were formed within this basin and at intervals within the flanking areas north and south of this probable west-northwest axis along which former land surfaces became depressed more than 11,000 feet. The west-northwest trending pre-Pennsylvanian, Chautauqua, and Barton arches of Kansas[1] probably have as their counterpart, south of this deep trough, the LlanoBurnet-"Concho divide" trend in Texas (Fig. 7). Thus the foundation available to the Carboniferous deposits was undoubtedly exceedingly complex both as to underlying rock masses and crustal weakness or strength.

That very exceptional conditions developed during the Carboniferous is demonstrated by the following comparative data.[2]

Age	*Areas of Greatest Accumulation*	*Maximum Thickness In Feet*
Cambrian-Ordovician	Southern Oklahoma	11,000
Silurian-Devonian	Southern Oklahoma	500
Carboniferous		
Pre-Morrow	Southeast Oklahoma	16,500
Morrow to close of Pennsylvanian	Southern Oklahoma	24,500
Permian	Southwest Texas	10,000
Triassic	West Texas	1,700
Jurassic	Southwest Texas	1,800
Comanche	Northeast Texas and Northern Louisiana	6,000
Upper Cretaceous	Northeast Texas	3,500
Tertiary	Texas Coastal Area	12,000
Quaternary	Texas Coastal Area	1,600

Whatever the causes and processes involved, it seems certain that every part of the Mid-Continent area was covered by Carboniferous deposits ranging from 500 to 25,000 feet in thickness, probably averaging

[1]J. S. Barwick, "The Salina Basin of North-Central Kansas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 12 (1928), pp. 177-89.

[2]Data taken mainly from *Oklahoma Geol. Survey Bull. 35* (1925), and *Univ. of Texas Bull. 44* (1916), Comanche thickness determined by Miss Alva C. Ellisor, Humble Oil and Refining Company; Triassic thickness, by L. D. Cartwright, Jr., *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 13 (1929), p. 172.

5,000 feet for the entire region. The sediments reveal that areas which were located within, or marginal to, the greatest accumulations were most susceptible to pronounced reversal of the general tendency toward subsidence, becoming, instead, areas of folding, uplifts, and denudation.

The areas of greatest deposition and structural change gradually shifted from the east to the west and southwest parts of the Mid-Continent region during the Carboniferous. The most prominent or notable type of deposit changed meanwhile from clastic to dissolved material, that is, from shales, sands, and conglomerates to limestone, dolomite, anhydrite, and salt. Thus the Carboniferous period seems to have witnessed extensive inundation of this region by shallow epeiric seas which became landlocked and desiccated extensively, and were finally eliminated from the region after inconceivably vast quantities of rock material had been shifted and profound structural changes produced in the earth's crust.

CONDITIONS CONTROLLING DEPOSITION

Ulrich[1] has stated that "the average depth of the Paleozoic seas was less than 200 feet and probably none attained depths exceeding 100 fathoms." Referring to the Carboniferous beds under study, this conclusion is fully justified by repeated appearance of shallow marine and brackish-water fauna, related at different times to the life of different oceanic areas; also by frequent alternations vertically, and transitions laterally, of shales, sandstones, and limestones, as well as by repeated occurrence of coal, conglomerate, gypsum, and salt, progressive overlaps, *et cetera*. The water being shallow, slight changes in sea-level or more probably of the earth's surface would cause wide advance or withdrawal of shore lines and in many ways affect the character of deposit. Wave and current action would produce irregular yet extensive distribution of whatever material arrived from the areas of erosion. The water of the invading seas doubtless contained various salts in solution, probably being saturated with carbonates as are the upper warm sea waters of to-day.[2]

The shallowness facilitated landlocking of larger or smaller parts of these seas and in other ways promoted precipitation of lime and finally of various other more soluble salts. Incoming streams and refills across low barriers from ocean areas could have furnished solutes in unlimited

[1] E. O. Ulrich, "Revision of the Paleozoic Systems," *Bull. Geol. Soc. Amer.*, Vol. 22 (1911), p. 362.

[2] F. W. Clarke, "The Data of Geochemistry," *U. S. Geol. Survey Bull. 770* (1924), p. 131.

quantities. Under conditions favoring oversaturation, the order of precipitation would be that of least solubility, namely, silica, limestone, dolomite, anhydrite, and salt. The fact that this sequence is broadly discernible upward through the Carboniferous deposits under study seems very significant.

SEDIMENTARY BASINS AND DEVELOPMENT OF STRUCTURE

Granted that these beds were deposited for the most part in shallow marine inundations, it follows that each bed originated approximately at sea-level. It also seems certain that sediments of a sea less than 200 feet deep and 100 miles, more or less, wide must have been laid down in nearly horizontal position. Consequently regional dips of more than a very few feet per mile are results of tilting after deposition.

When large areas are studied, it is evident that deposits of a given period vary in thickness, some to an amazing degree, as shown by the isopach maps (Figs. 1-6). Tilting of all earlier beds toward the area of greatest thickness of each subsequent basin must occur, and these changes, with the compensating uplift around the basin areas, probably explain the origin of most regional dips. Important changes of sea-level seem improbable because of the great expanse of sea areas. Basin-shaped accumulations of sediments, the oscillating migratory nature of the basins, and the ample proofs of changed positions of parts of the lithosphere through long periods of time are strong evidence for relative stability of sea-level and variability of the position of the earth's crust in continental areas. The coarse character of much of the sediments of these basins seems to prove that extensive subsidence of one area goes on concurrently with extensive uplift of other areas near it. This calls for nearly contemporaneous decrease of volume beneath the subsiding basin and increase of volume in the area of uplift and erosion. As will be discussed under "Structural Studies," the most plausible explanation for these volume changes seems to be lateral migration of plastic material in the subcrustal zone from the area of subsidence to the area of uplift (Fig. 9).

SEDIMENTARY RECORD

To decipher more clearly the successive most important developments, the Carboniferous beds under study are divided into groups, division being made largely at unconformities and recurrence of excessively coarse material, it being thought that the character and distribution of the sediments and the differences of folding observed in the successive

groups would give definite evidence of the controlling developments of the region. The main sources of intersectional correlations of beds are the bulletins of the United States Geological Survey—particularly the "Tentative Correlation" charts (1925),— Oklahoma Geological Survey, and Bureau of Economic Geology and Technology of the University of Texas.

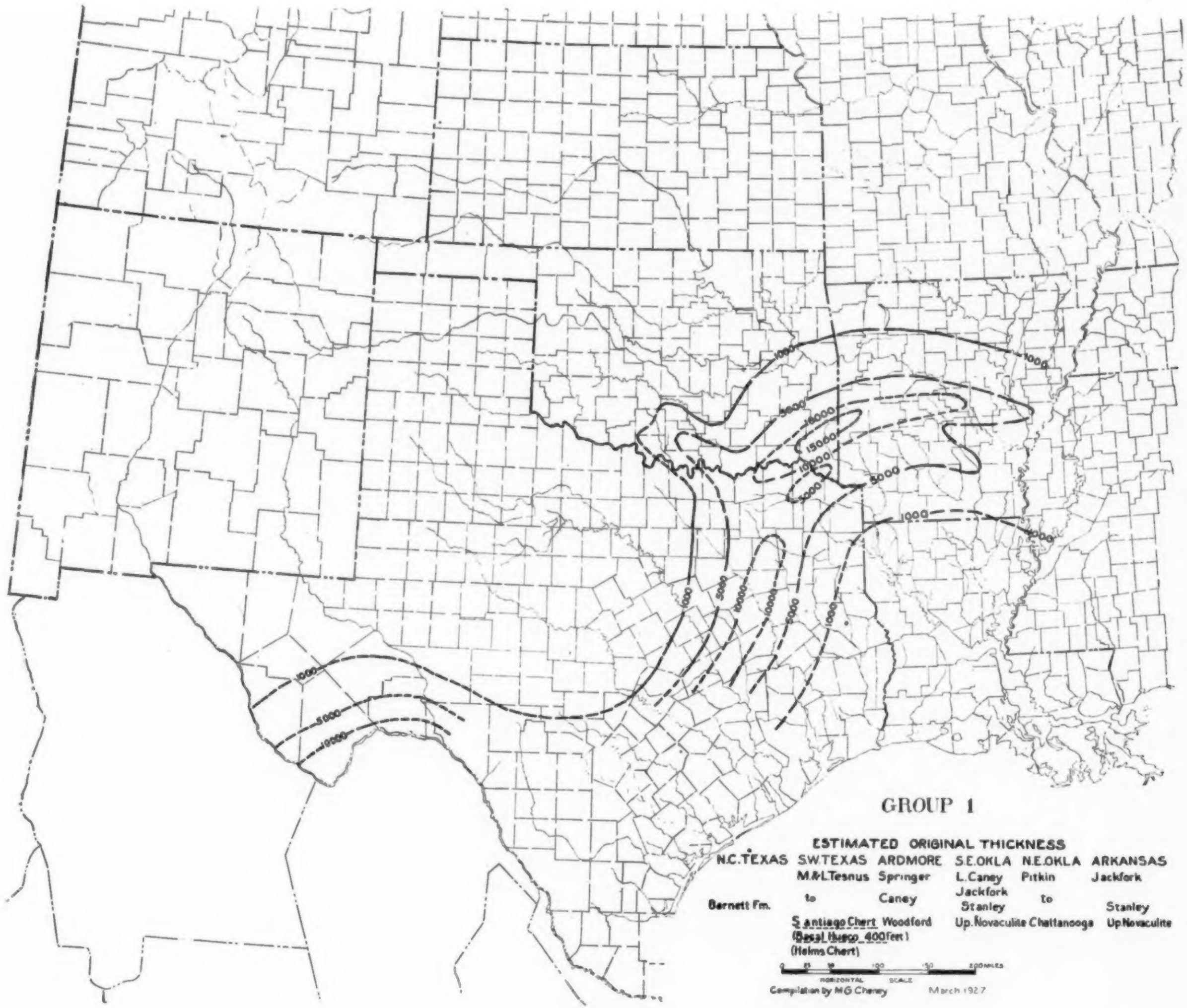
To depict more accurately the vertical and lateral extent of each group, isopach maps have been prepared from data obtained from the sources mentioned and others too numerous to list. These maps are intended to show in an approximate way the original thickness of sediments deposited during the successive chosen periods. Circumstances require many deductions and these are made largely upon the basis of character of deposits, probable source of material, and depositional and structural analogies. It seems practicable to divide these beds into six groups, but preferable to discuss them by three larger divisions according to basin developments to which they were mainly related.

PERIOD DOMINATED BY OUACHITA-ARDMORE-MARATHON BASIN DEVELOPMENT

EARLIEST MISSISSIPPIAN TO ATOKA BEDS

The sediments of group 1 (Fig. 1) are mainly or entirely Mississippian, being older than the Morrow, Wapanucka, and Marble Falls beds; group 2 (Fig. 2) are early Pennsylvanian (Pottsville) and include all beds believed to be of Wapanucka and Atoka age. The study of these periods is of the greatest importance, for the main structural features of more than half of the Mid-Continent region were fashioned and largely developed at this time. Discussion of these beds and periods is limited to the general features considered most pertinent to the identification of the more important regional developments.

The Chattanooga shale, usually accepted as the oldest marine deposit of the Carboniferous, evidently follows a period of nearly complete base-levelling of the interior United States. It is remarkably lacking in coarse material for so extensive an overlap; is known to overlap beds from Devonian to Cambrian in age and extend from the Appalachian region well into or across Oklahoma and Kansas. Several hundred feet of these and later marine deposits of Mississippian age were laid down in the areas now known as the Ozark and Llano-Burnet uplifts, the Ouachita, Arbuckle, Nemaha, Marathon, and Guadalupe Mountains, and probably the Wichita and Amarillo Mountains and all intervening areas. It is not meant, however, to imply that the entire region was



1000
5000
10000
15000
GROUP 1
ESTIMATED ORIGINAL THICKNESS
N.C. TEXAS
Barnett Fm.
SW. TEXAS
M.&L. Tesnus
to
Santiago Chert
(Basal Hueco 400 Feet)
(Helms Chert)
ARDMORE
Springer
Caney
Woodford
S.E. OKLA
L. Caney
Jackfork
Jackfork
Stanley
Stanley
Up. Novaculite
N.E. OKLA
Pitkin
to
Chattanooga
ARKANSAS
Jackfork
Stanley
Up. Novaculite
HORIZONTAL SCALE
Compilation by M. G. Cheney
March 1927

FIG. 1

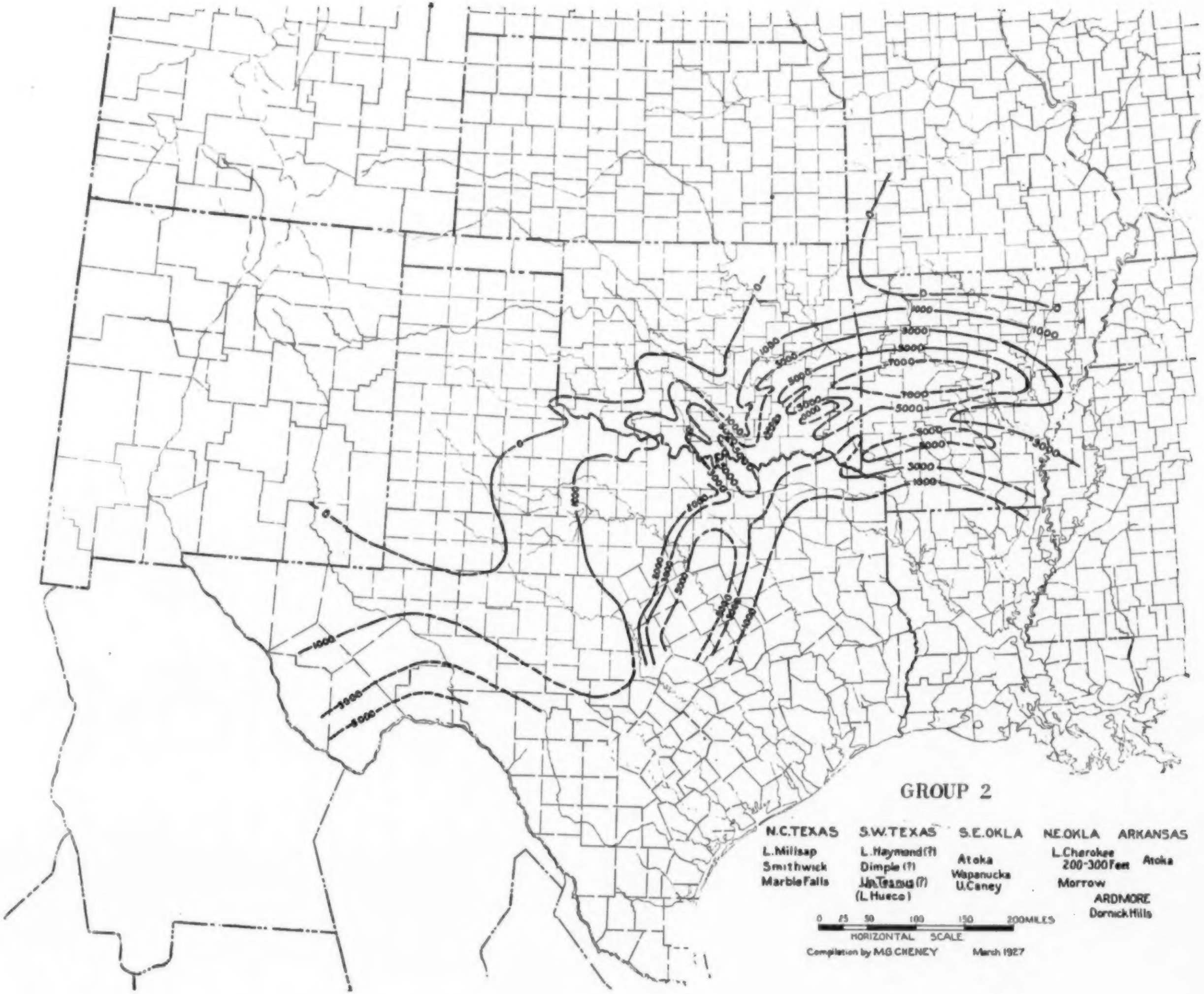

GROUP 2
N.C.TEXAS
L.Millsap
Smithwick
Marble Falls
S.W.TEXAS
L.Haymond (?)
Dimple (?)
Up.Tesnus (?)
(L.Hueco)
S.E.OKLA
Atoka
Wapanucka
U.Caney
NE.OKLA
L.Cherokee
200-300 Feet
Morrow
ARKANSAS
Atoka
ARDMORE
Dornick Hills
0 25 50 100 150 200 MILES
HORIZONTAL SCALE
Compilation by M.G.CHENEY
March 1927

FIG. 2

necessarily below sea-level at any given time. These epi-continental seas were probably oscillatory, being affected by many crustal movements of small vertical changes but wide areal effect.

Extensive bedded chert deposits of the Ouachita, Arbuckle, and Marathon districts, and an unknown part of the intervening area form a notable part of Ordovician, Devonian, and earliest Mississippian deposits, seemingly being limited to the southeast part of the region under study, a circumstance very helpful in determining the structural history of these areas which at some later date witnessed such great orogenic movements. A thin series of bedded chert resembling Woodford chert and overlying the Ellenburger limestone has been noticed by P. M. Martin and the writer 5 miles southwest of Lampasas on the northeast slopes of the Llano-Burnet uplift in central Texas.

In contrast to the quiet conditions and comparatively thin shale and limestone deposits of early Mississippian time there came the volcanic deposits of the lower Stanley and vast quantities of muds and sands to form the Stanley, Jackfork, and Atoka beds. Honess[1] reported these shales and feldspathic sandstones and grits to be more than 20,000 feet thick in northern McCurtain County, Oklahoma; and concluded "that the direct source of the Stanley sediments was a land area consisting in large measure of acid igneous and metamorphic rocks, for in practically all of the sandstones examined, bits of fresh acid plagioclase occur;" that the Stanley was "deposited by slow-moving waters and in a region considerably removed from the land mass furnishing the material;" and that the vegetal remains noted in the upper Stanley and Jackfork "floated down stream from land areas to the south and southeast and out upon the delta to the north where they were engulfed in the sands."

Honess evidently concluded from his extensive field work that the main source of these Stanley and Jackfork beds lay at the south; also, that the main compressive forces came subsequently from this same direction.

Miser[2] attributed these clastic sediments and tuffs to the rejuvenation of "a Paleozoic land area that occupied at least a part of Louisiana and eastern Texas." Like numerous other authorities who had devoted years of study to these areas and to whose writings he refers, Miser saw

[1] C. W. Honess, "Geology of the Southern Ouachita Mountains of Oklahoma," *Oklahoma Geol. Survey Bull. 32* (1923), pp. 196-202; "Geology of Southern LeFlore and Northwestern McCurtain Counties, Oklahoma, *Bur. Geol. Circ. 3* (1924).

[2] H. D. Miser, "Llanoria, the Paleozoic Land Area in Louisiana and Eastern Texas," *Amer. Jour. Sci.*, Vol. 2 (August, 1921), pp. 61-89.

conclusive evidence in the field that these vast quantities of clastics were derived chiefly from the south and southeast.

He states:

> This northward thinning of the sandstone beds of the Stanley shale and dovetailing of thick beds of shale in the Jackfork sandstone to the north imply a southern source for the sand and mud that later formed these formations. Many small quartz pebbles, one-fourth inch or less in diameter, occur in the Jackfork sandstone, particularly in the lower part, on the southern border of the Ouachita Mountains. They become less abundant toward the north.

This problem of source of the material is considered fully as important to these studies as that of accumulation. Although it is exceedingly hazardous to compare conditions affecting these ancient shallow epicontinental seas with present gulf, mediterranean, or deep oceanic areas, it nevertheless seems logical to assume that erosion areas from which these ancient sediments were being derived were ordinarily much larger than the areas of deposition. If these conditions existed, the large distant land area of Stanley time referred to by Honess may have extended well into or even across the region now occupied by the Gulf of Mexico. The evident migration of basins and of erosion areas throughout Carboniferous time supports the evidence furnished by the increasing coarseness of the sediments that these erosion areas advanced gradually northward during Stanley, Jackfork, and Atoka times.

Evidence from deep wells shows conclusively that some erosion was occurring in the northwest parts of Texas and Oklahoma and western Kansas during late Mississippian and early Pennsylvanian. However, the amount of material derived from this source is in doubt, perhaps being little more than sufficient to supply the developing Ardmore basin and Cherokee trough which seem to have persisted through these periods. In some places, it is difficult to determine how much of the erosion now noticed in these western areas occurred later than Chattanooga rather than before. The resistant nature of most of the pre-Carboniferous beds which were there subject to erosion, and the increase of limestone and fine sediments deposited close to these western shores during Mississippian and early Pennsylvanian times are strong evidence against derivation of large quantities of clastics from areas on the west.

In studying the isopach maps of these and later periods it should be borne in mind that such data indicate not alone the approximate thickness of beds deposited, but also the amount of subsidence of all older rocks lying upon or within the resistant crust, and further, the amount of regional dips developed in the underlying beds during given

periods. Conversely, the thickness of beds eroded from areas around the basin indicates the approximate amount of uplift and tilting which occurred there.

It is thought that these negative and positive movements of the crust must be nearly compensating in volume. To accomplish this, subcrustal migration under abnormal pressures must take place and crustal rocks must undergo much fracturing, hence weakening, as former plane surfaces take on arcuate form and change their vertical positions thousands of feet. In view of the variations in crustal strength and subcrustal pressures, it is not surprising to find that the basin areas subsided irregularly and that the uplift areas show many local structural features. Known examples of the former are the Criner Hills in the Ardmore basin and the Black Knob Ridge in the northwestern Ouachita region, which contributed conglomerates locally to the Dornick Hills and Atoka beds, respectively. Irregularity of uplift may be seen in the Ozark and Nemaha Mountains, Cushing, Seminole, and many other uplifts and sharp folds which were developing and suffering erosion in the areas of general uplift on the north and northwest as the great Ouachita basin subsided. However, most of the compensating displacement of subcrustal volumes very probably occurred toward the region of main erosion on the south (Llanoria). For reasons which seem quite evident, the upper rocks of this deeply subsiding basin must have become gradually weaker and lighter with reference to the rising areas marginal to it (Fig. 9).

The more or less local uplifts which develop within the basins in contrast to the prevailing tendencies of tension and subsidence and prior to the time of orogenic movements, must be nearly vertical in nature, being the result of some temporary reversal of pressure conditions, and probably accompanied by oscillation of the basin area. Such comparatively local, though in some cases extensive features, may cause great changes in beds and faunas within short distances. If orogenic folding affects the area later, the amount of crustal shortening and overthrusting may be considerably overestimated. Overthrusting in the Ouachita area has been estimated at scores of miles on the basis of dissimilarity of pre-Carboniferous sediments in the Arbuckle, Stringtown, and McCurtain districts.

The Caney "boulders" of the Ouachita district of southeast Oklahoma seem to be good evidence of irregular subsidence of parts of that area. It seems to the writer that they must be explained by the presence

of the Arbuckle type of rocks beneath parts of the Ouachita area, the development of local sharp folds and faulting in pre-Caney or early Caney times, permitting the invading Caney sea to erode the projecting rocks and distribute, by wave action in a shallow sea, the derived rock fragments. The rock gouges assigned to glacial or ice action may have been caused by the harder cherts scoring other beds during faulting movements. The presence of boulders with maximum dimensions of $269 \times 65 \times 20$ feet in Johns Valley, 30 miles east of Atoka, and their small size or absence from equivalent shales of the Arbuckle region, seem to preclude the Arbuckles as their source. Ulrich[1] has identified eighteen formations of the Arbuckle district ranging in age from Cambrian to Devonian, with southern, eastern, and northern fauna relationships, arriving, he says, by three major invasions from the east. It seems clear that some connecting seaways must be provided. It is believed that this interpretation largely agrees with views expressed by Powers, Page, and others at the Annual Meeting of the American Association of Geologists at Tulsa in 1927.

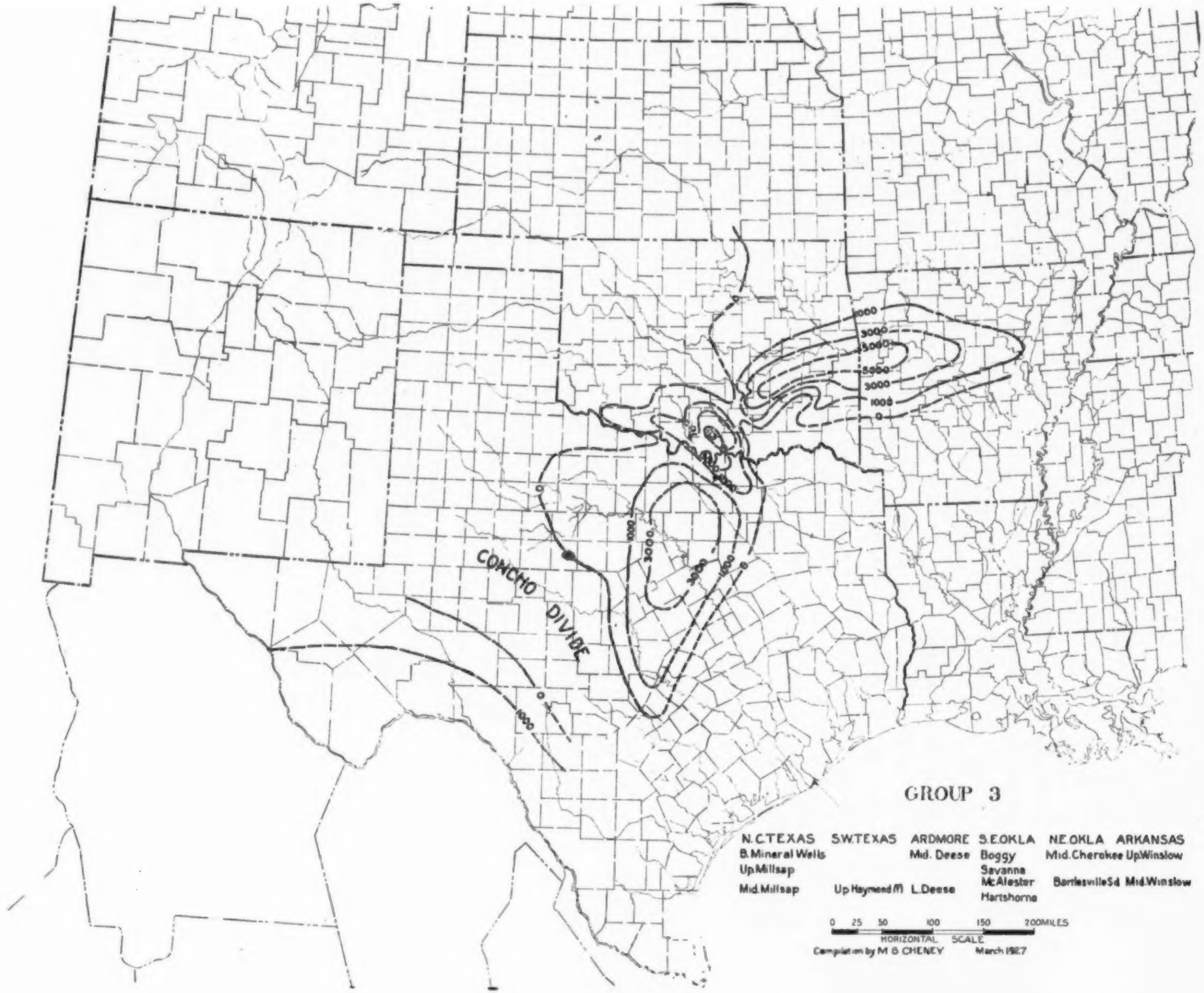
It is conjectured that the Ouachita basin extended far southwestward into Texas, possibly connecting with the Marathon basin of southwest Texas. The southeast origin of sediments makes such extensions seem probable, and this belief is supported by the similarities of structure as determined in Texas by well records (Fig. 7); and similar structure under the circumstances is taken to mean similar depositional history. Post-Jurassic subsidence (Fig. 8) has done much to obscure this southwest extension of Woodford, Stanley, Jackfork, and Atoka deposits.

A tendency toward restriction of areas of deposition is noted during the later part of group 2 period and the question may be raised as to whether at least the upper Atoka was not accumulating in several local basins rather than continuously throughout the large area indicated in Figure 2.

PERIOD DOMINATED BY MCALESTER-ARDMORE-STRAWN BASINS HARTSHORNE TO BOGGY

This third group of deposits (Fig. 3) was evidently more restricted in occurrence than any other group. Sediments, almost entirely clastics, accumulated to a thickness of more than one mile in the McAlester (Arkansas Valley-Lehigh) basin northwest and north of the preceding Ouachita basin, and nearly two-thirds this thickness in the Ardmore and

[1] E. O. Ulrich, "Revision of Cambrian-Devonian Beds of Arbuckle-Wichita Region," *Geol. Soc. Amer.*, Annual Meeting (December, 1928).



CONCHO DIVIDE
1000
3000
5000
0
GROUP 3
N.C.TEXAS
B.Mineral Wells
Up.Millsap
Mid.Millsap
SW.TEXAS
Up Haymond(?)
ARDMORE
Mid. Deese
L.Deese
S.E.OKLA
Boggy
Savanna
McAlester
Hartshorne
N.E.OKLA
Mid.Cherokee
BartlesvilleSd
ARKANSAS
Up.Winslow
Mid.Winslow
0 25 50 100 150 200MILES
HORIZONTAL SCALE
Compilation by M G CHENEY
March 1927

FIG. 3

Strawn basins. This group is thought to be mostly or entirely Allegheny in age.

The available sedimentary and structural evidence indicates that the main folding and initial uplifting of the Ouachita basin region occurred during this third period. (The main Marathon disturbance is thought by some to have occurred somewhat later.)

The sedimentary evidence includes the increasing prevalence of a new type of coarse material. The coarse quartz and fresh feldspars and metamorphic detritus of earlier beds indicated a stripping of sediments from the land areas mentioned under the term "Llanoria." Chert conglomerates had been wholly lacking except the bed in the earliest Stanley, and those derived locally, as from Black Knob Ridge, but groups 3, 4, and 5 display an increasingly great quantity of these very coarse fragmental materials on the east margins of their areas of deposition, from Colorado River of central Texas to the McAlester-Beggs districts in Oklahoma. Meantime feldspars diminished prior to the time of group 5 beds, when granitic rocks of the Arbuckle, Wichita, and Amarillo Mountains became exposed. Llanoria is therefore eliminated as a possible source for this new type of deposit, as are also the Ozarks, Arbuckles, Llano-Burnet, and areas on the west or northwest, for none of these could provide an adequate supply or the necessary variety of chert (including green, red, banded, *et cetera*), or a rock surface sufficiently favorable to the rapid erosion which evidently took place. The Ouachita area, with its alternating thin chert and shale beds ranging from 1,200 to 1,600 feet in thickness, meets all requirements and is properly located geographically to explain best the observed distribution of material. Drake[1] concluded that an eastern or northeastern area supplied the materials for the post-Bend deposits of the Colorado coal field of Texas, and Taff[2] notes that various members of the beds ranging from Hartshorne to Boggy are chert conglomerates on the east, or Ouachita, side of the Lehigh basin, but repeatedly change to fine, even-grained sands on the southwest, or Arbuckle side.

In southeast Palo Pinto County, Texas, the coarse chert conglomerates of the Brazos River sandstone and conglomerate beds are much cross-bedded, having the steep foreset beds pitching westward, as is the rule for other occurrences of this nature, in this region. The chert fragments may be seen to decrease in size westward along an extensive

[1] N. F. Drake, "Report on the Colorado Coal Field of Texas," *Geol. Survey of Texas 4th Ann. Rept.* (1892), pp. 15-16.

[2] J. A. Taff, *U. S. Geol. Survey Geol. Atlas*, Atoka Folio, No. 79 (1902).

east-west outcrop, being entirely replaced by normal sandstone before the southwest part of the county is reached, as shown by the large areal map by Plummer and Moore.[1]

If the greater Ouachita area supplied the vast quantity of these coarse clastics, and it seems certain that it did, there must have been extensive folding and uplifting of that area and sand and shale deposits thousands of feet thick removed before these underlying cherts could have been extensively eroded. Seemingly great orogenic movements which converted the weakened Ouachita basin into a synclinorium (syncline-mountains of Dana) began as early as late Atoka time, and developed most actively from Hartshorne to Boggy times, possibly exerting some thrusting influence even later, as thought by some authors. Sharp folds with northeast-southwest axes are noted in north-central Texas nearly as late as the close of Strawn time, which corresponds very well with the following observations by Clawson.[2]

> The large steeply folded structural features typical of the Coalgate-McAlester area and associated with the Ouachita overthrust were well developed by middle and late Boggy times, subsequent folding consisting of a tilting and warping with compressive forces acting from the northeast and southwest, rather than from the direction of the Ouachita mass to the southeast.

As the deep, narrow Strawn and McAlester coal basins developed beneath the accumulating sediments of late Pottsville and Allegheny times, the underlying Bend-Wapanucka-Morrow and older beds must have become flexed along the northwest margin of the areas of great subsidence, the upward side having remained a low plateau, as indicated by the few hundred feet of denudation which occurred there during this period, and by the horizontally deposited overlap beds which show close parallelism with underlying early Pennsylvanian or Mississippian beds of the plateau (Figs. 2, 3, and 7). Subsequent westward tilting toward centers of later Pennsylvanian and Permian basins and away from the extensive uplift of the Ouachita synclinorium has tended to give these flexures the appearance of arched uplifts, as illustrated ideally by Levorsen.[3]

The terms "Bend flexure" and "Tahlequah flexure" are introduced to depict more correctly these features which never were arched uplifts

[1] F. B. Plummer and R. C. Moore, "Stratigraphy of the Pennsylvanian Formations of North-Central Texas," *Univ. Texas Bull. 2132* (1921).

[2] W. W. Clawson, Jr., "Oil and Gas Geology of Coal and Pittsburg Counties," *Oklahoma Geol. Survey Bull. 40-JJ* (1928), p. 14.

[3] A. I. Levorsen, "Convergence Studies," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 11 (1927), Fig. 15, p. 681.

and which evidently have suffered no change except continental tiltings and local folding since their formation. The eastern part of the Tahlequah flexure has been least affected by westward tilting.

Unquestionably certain progressive changes during Mississippian and Pennsylvanian times did produce several rather extensive arched folds which may well be labelled "arches." The Hunton arch[1] of south-central Oklahoma lies between deep basins which formed on the east during the time represented by groups 1-3, and on the southwest by groups 1-4. It was tilted westward during groups 5 and 6. The Muenster and Electra arches along Red River in north-central Texas are believed to have originated no later than early Paleozoic, for they do not seem to have received the thick pre-Carboniferous deposits observed in the Arbuckles. The main structural differentiation, however, came with the development of the deep Ardmore basin on the north and the shallower Strawn basin on the south, the total structural relief developed by the Muenster arch having been not less than 5 miles to the northeast and 1½ miles to the southwest. Available evidence indicates that these arches became conspicuous chiefly because of less subsidence than the flanking areas and in a minor degree because of occasional uplift. Exceptionally strong vertical movements affected certain areas along this trend in late Canyon and early Cisco times, involving especially the northeast flank of the Ardmore basin and leading to the prominent uplift of the Arbuckle Mountains at this time. Tomlinson[2] has emphasized the need of differentiating carefully between the different periods of folding, also between the eastern and western parts of the Arbuckles.

The eastern part was affected by repeated minor oscillations and received comparatively thin deposits from the Silurian to the late Pennsylvanian, as reported in detail by Morgan,[3] while the western part received very thick accumulations of beds included in groups 1-4.

The arches, mountains, and folds showing such continuous alignment, with trend north-northwest, parallel with that noticed in pre-Carboniferous beds in Kansas and the pre-Cambrian of the Llano-Burnet uplift, are naturally considered as situated on old lines of weakness.

The term "Muenster arch" is meant to designate the very pronounced structural trend which is known to extend from northeast

[1]Robert Dott, "Pennsylvanian Paleogeography," *Oklahoma Geol. Survey Bull. 40-J* (1927).

[2]C. W. Tomlinson, "Oil and Gas Geology of Carter County," *Oklahoma Geol. Survey Bull. 40-Z* (1928).

[3]George D. Morgan, "Geology of the Stonewall Quadrangle, Oklahoma." *Bur. Geol. Bull. 2* (1924).

Denton, through western Cooke and northern Montague counties, Texas, probably formerly continuing to the granite peaks area south of the present Wichita Mountains. It is believed that the first well to penetrate the buried Ordovician rocks of this large structural feature was drilled at Muenster, Texas. The "Electra arch" extends from the Petrolia uplift in northern Clay County through northern Wichita, central Wilbarger, and at least as far west as northeast Foard County, Texas. A contour map of these features and their relation to folded areas of southern Oklahoma was published in the *Oil and Gas Journal*,[1] which publication carried a much earlier article upon this subject by Hager.[2] The Cisco, Canyon, and possibly Strawn beds are yielding oil on the Muenster arch, whereas only the first of these is now producing on the Electra arch. Accumulations of oil in pre-Carboniferous beds are present locally in the region south of these two arches and most prolifically on and north of the Hunton arch, yet, to date, are unknown on the Muenster and Electra arches. There are several possible causes for this, such as lack of petroliferous overlap, leakage during long erosion intervals, and upward migration into overlying sands.

A very broad, low arch seems to have been formed during Mississippian and early Pennsylvanian times, trending northwest from the present Llano-Burnet uplift and between the Ouachita-Strawn basins on the northeast and the Tesnus-Haymond basins on the southwest. This is indicated as the Concho divide in Figures 3 and 7. Pre-Carboniferous beds are expected to lie not far below upper Pennsylvanian on this trend of less subsidence.

PERIOD OF DEVELOPMENT OF BROAD WESTERN BASINS
THURMAN TO CLOSE OF PERMIAN

Morgan[3] and others have pointed out the change of strike beginning with the Thurman sandstone. These beds of sand, conglomerate, and shale are not involved in the folds typical of the McAlester coal basin, but, like later beds, dip westward except as influenced by the Arbuckle uplift and by local folds of the ordinary Mid-Continent type.

The Brazos River sand and conglomerate in north-central Texas seem to be the logical correlative of the Thurman sand of Oklahoma.

[1] M. G. Cheney, "Pre-Mississippian Production in North-Central Texas," *Oil and Gas Jour.* (April 12, 1928), pp. 31-33.

[2] Lee Hager, "Red River Uplift Has Another Angle," *Oil and Gas Jour.* (October 17, 1919), pp. 64-65.

[3] George D. Morgan, "Geology of the Stonewall Quadrangle, Oklahoma," *Bur. Geol. Bull. 2* (1924), p. 85.

Both chert conglomerates and limestone deposits become increasingly conspicuous in the overlying Pennsylvanian beds. As these conglomerates in many places show removal of 10-30 feet of underlying beds but themselves grade into normal sands westward, they are considered as deposits along eastern shore lines, and as their occurrence is recorded farther and farther westward during the upper Pennsylvanian, they seem to offer definite proof of uplift of the Ouachita synclinorium and of its extensive denudation. The intermittent oscillatory nature of uplift and subsidence is indicated by the alternation of conglomerates, sands, shales, and limestones. It is interesting to notice that some of this coarse chert material becomes embedded in limestone ooze prior to solidification.

The western shores of these upper Pennsylvanian seas were likewise gradually migrating westward. Upper members of Group 4 and beds of Group 5, chiefly in the form of limestone deposits, are known to extend into western parts of Kansas, Oklahoma, and Texas, throughout most of New Mexico, and large areas on the west and northwest. These upper Pennsylvanian and Permian seas are distinct from their immediate predecessors not only in more westerly location and far greater extent, but in the very abnormal quantities of dissolved material being deposited, which seems to be rather conclusive that connection with oceanic areas had become lost or restricted by uplifts bordering these epeiric seas. Probably climatic conditions also promoted precipitation of the soluble material, this meaning lower temperature[1] as well as less rainfall. Inconceivably great deposits of lime, dolomite gypsum or anhydrite, and salt followed one another, interbedded with more or less shale and irregular sandstone members, this clastic element increasing in prominence as the Wichita Mountain trend or eastern or western marginal areas are approached. This very definite influence of the Arbuckle, Wichita, and Amarillo Mouutains appears as early as late Canyon and persists long into the Permian. The Ouachita synclinorium, which developed mostly in Allegheny time, evidently continued to rise as the Permian basin area progressively subsided. These great tilting movements were more prominent in Texas than farther north, for the greatest subsidence occurred in southwest Texas, and evidently the greatest erosion in east-central Texas, where stripping proceeded to the pre-Cambrian schists rather than to the Cambrian only, as in southeastern Oklahoma. The sagging of this great basin area was sufficient to permit

[1]Charles Schuchert, "Review of the Late Paleozoic Formations and Faunas, with Special Reference to the Ice Age of Middle Permian Times," *Bull. Geol. Soc. Amer.*, Vol. 39 (1928), pp. 769-886.

burial of the Amarillo Mountains beneath Permian sediments more than ½ mile thick. The Amarillo, Wichita, and Arbuckle Mountains shed much arkosic material during the late Pennsylvanian and the early Permian, which has served as oil and gas reservoirs along these buried granite masses in the Amarillo region. These arkosic inmixtures are first noticed immediately above the Saddle Creek limestone (middle Cisco) in Texas and in the Vanoss formation (basal Pontotoc terrane) in southern Oklahoma.

Figures 4, 5, and 6 give some idea of the structural developments of these upper Carboniferous times. It seems from these data that the subsidence of these western basin areas reached a maximum in excess of 10,000 feet, the contemporaneous eastern marginal uplift perhaps exceeding this figure, a differential movement of approximately 4 miles. Meantime, comparatively minor movements were occurring in other parts of the Mid-Continent area. As previously mentioned, the main Arbuckle, Wichita, Amarillo, and ancestral Rocky Mountain areas were being strongly upfolded near the close of group 4 and the beginning of group 5. Also, at this time or a little later, certain major movements were affecting the Marathon Mountain region, for progressive overlaps in short distances show the absence of nearly ½ mile of lower Permian, according to Beede.[1] The continuous San Angelo-Duncan conglomerate and sand deposits are considered evidence of westward advance of the eastern shore lines and of some accentuation of upward movement along eastern margins of this great basin. The 2,000 feet of sand deposits of lower Delaware decreasing northward from the Guadalupe Mountains indicate uplift flanking this Permian basin on the southwest.

It is interesting to notice the gradual migration of the salt-depositing areas. The salt deposits of Utah and Iowa are late Pennsylvanian; those of western Oklahoma, central New Mexico, and north-central Texas are Permian, older than San Angelo; while those of west Texas and southeast New Mexico are Permian, later than San Angelo. The absence of these salt deposits and presence of an upper Permian limestone section of the Marathon region is noteworthy.

Prolific oil fields of Kansas and Oklahoma (including Burbank, Healdton, *et cetera*) from sands younger than the Bartlesville, and at least two-thirds of the production of north-central Texas, have been developed from these beds of upper Strawn, Canyon, and Cisco age (groups 4 and 5). The extensive Panhandle field is producing from

[1] J. W. Beede, conversation.

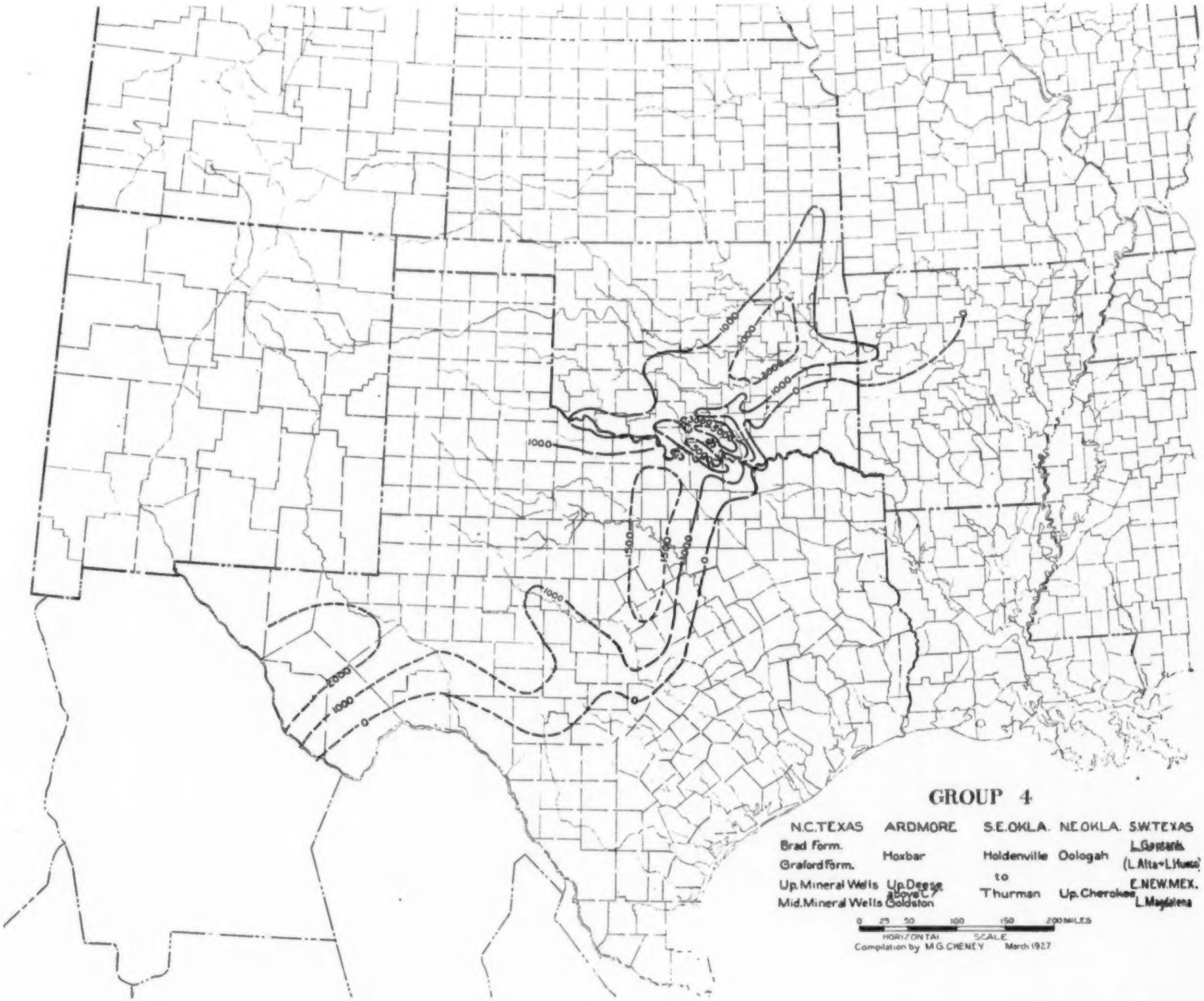

GROUP 4
N.C.TEXAS
Brad Form.
Graford Form.
Up. Mineral Wells
Mid. Mineral Wells
ARDMORE
Hoxbar
Up. Deese above C7
Goldston
S.E.OKLA.
Holdenville
to
Thurman
NE.OKLA.
Oologah
Up. Cherokee
S.W.TEXAS
(L.Alta+L.Hueco)
E.NEW.MEX.
0 25 50 100 150 200 MILES
HORIZONTAL SCALE
Compilation by M.G.CHENEY March 1927

FIG. 4

FIG. 4

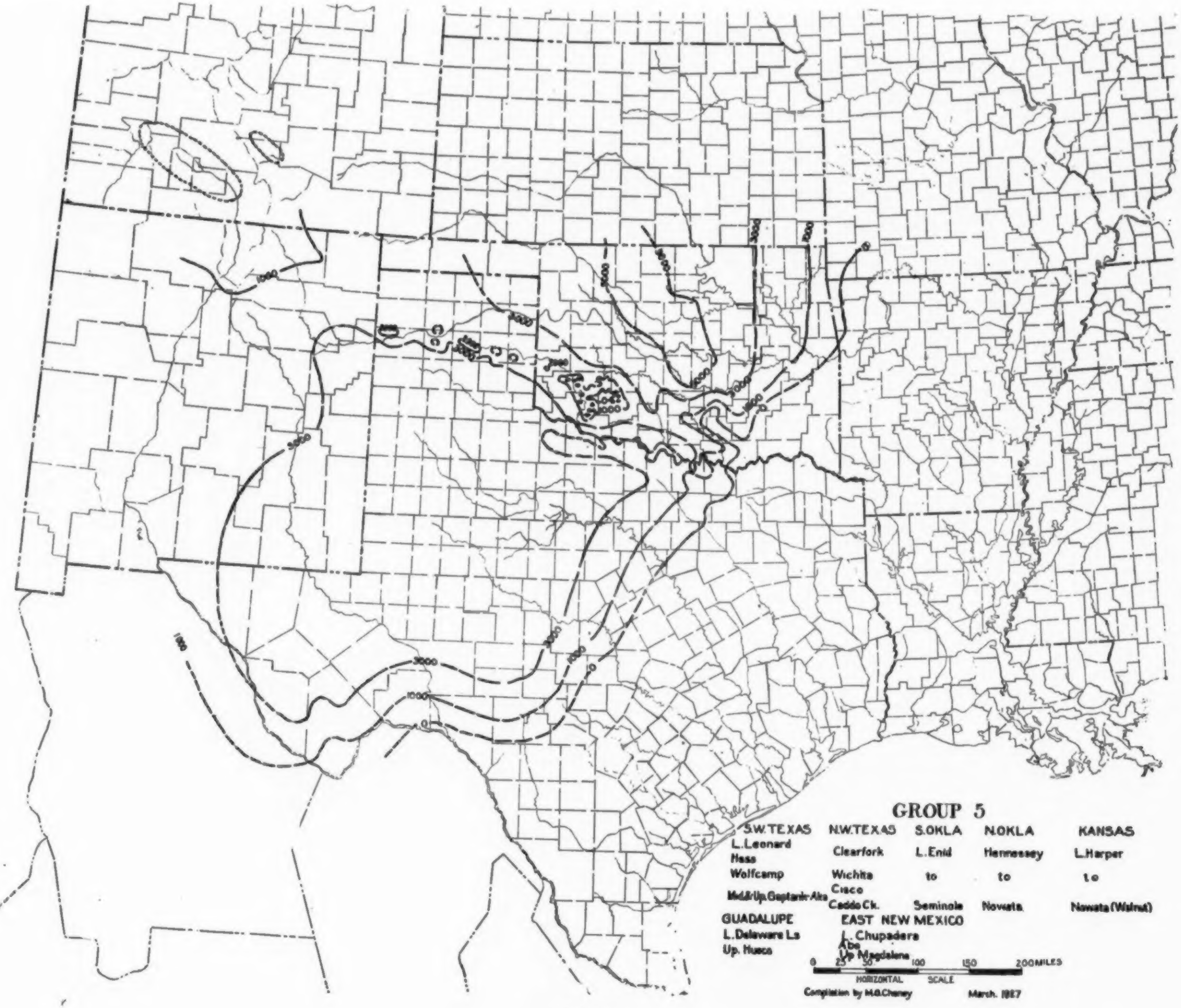

GROUP 5
S.W. TEXAS
L. Leonard
Hess
Wolfcamp
Md.&Up. Gaptank-Abo
GUADALUPE
L. Delaware Ls
Up. Hueco
N.W. TEXAS
Clearfork
Wichita
Cisco
Caddo Ck.
EAST NEW MEXICO
L. Chupadera
Abo
Up. Magdalena
S. OKLA
L. Enid
to
Seminole
N. OKLA
Hennessey
to
Nowata
KANSAS
L. Harper
to
Nowata (Walnut)
0 25 50 100 150 200 MILES
HORIZONTAL SCALE
Compilation by M.G. Cheney
March, 1937
3000
1000
0

FIG. 5

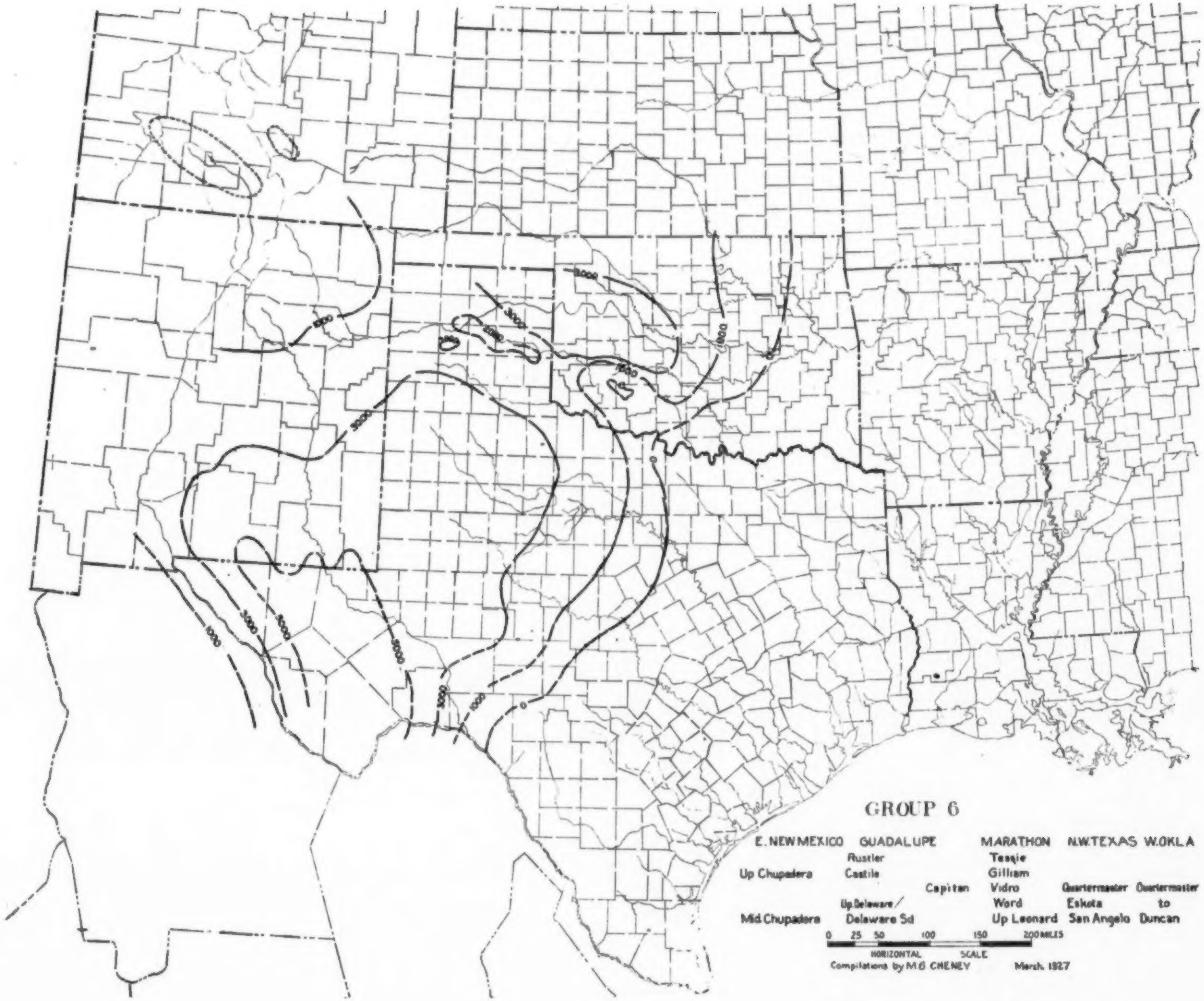

GROUP 6
E. NEW MEXICO GUADALUPE MARATHON N.W. TEXAS W. OKLA
Up Chupadera
Rustler
Castile
Up Delaware / Delaware Sd
Capitan
Mid Chupadera
Tesnie
Gilliam
Vidro
Word
Up Leonard
Quartermaster
Eskota
San Angelo
Quartermaster to Duncan
0 25 50 100 150 200 MILES
HORIZONTAL SCALE
Compilations by M.G. CHENEY
March, 1927

FIG. 6

Cisco and lower Wichita (group 5), and the extensive oil fields of west Texas are developed from beds younger than the San Angelo (group 6).

POST-CARBONIFEROUS DEVELOPMENTS

The Carboniferous sediments heretofore reviewed must have been influenced to a considerable degree by post-Carboniferous developments. Basins continued to form in the west part of the Mid-Continent area during parts of Triassic and Jurassic times, as indicated in an earlier table. No very important changes seem to have developed, however, until the Comanche, when a marine inundation from the south advanced first into the Rio Grande and east Texas areas, finally by slow progressive overlap encroaching upon all parts of the region. Thicker deposits accumulated, that is, greater subsidence of old surfaces occurred, during both the Mesozoic and Cenozoic eras in the Rio Grande, east Texas, and Mississippi Valley embayments than elsewhere, except that Upper Cretaceous and Eocene series developed their greatest thickness in the Rocky Mountain region. It is difficult to determine the full amount of structural change of these later periods, but if it be assumed that a peneplain existed at the beginning of Comanche time without gradient in the northeast and southwest directions, it would seem, as illustrated by Figure 8, that broad troughs and arches have formed, for this old surface is more than a mile below sea-level at Eagle Pass, ¼ mile above sea-level in the Llano-Burnet district, 1 mile below sea-level in northeast Texas, ½ mile above sea-level in the Boston Mountains of northwest Arkansas, and near sea-level again at the south end of Illinois. An east-west section from southeast New Mexico to coastal Texas shows differential movements exceeding 3 miles. To some extent this may indicate erosion or irregularities of the old surface, yet it must be noted that the Basement sands of the Comanche series are thinnest in the former basin area of west Texas and thickest in former erosion areas along the Balcones fault zone; hence, the reversal was probably even greater than indicated by the present configuration of this old surface.

The much discussed fault trends of central Oklahoma and less discussed similar trends of north-central Texas (as from north Palo Pinto to south Throckmorton counties), but with direction of trend nearly east-west instead of nearly north-south, may have some relation to this east Texas embayment. Also central Oklahoma seems to have been elevated less since Cretaceous time than the areas on the east and west. Faults and local folds of these parts of Oklahoma and Texas affect Permian beds laid down after the folding of the Arbuckle, Wichita, and

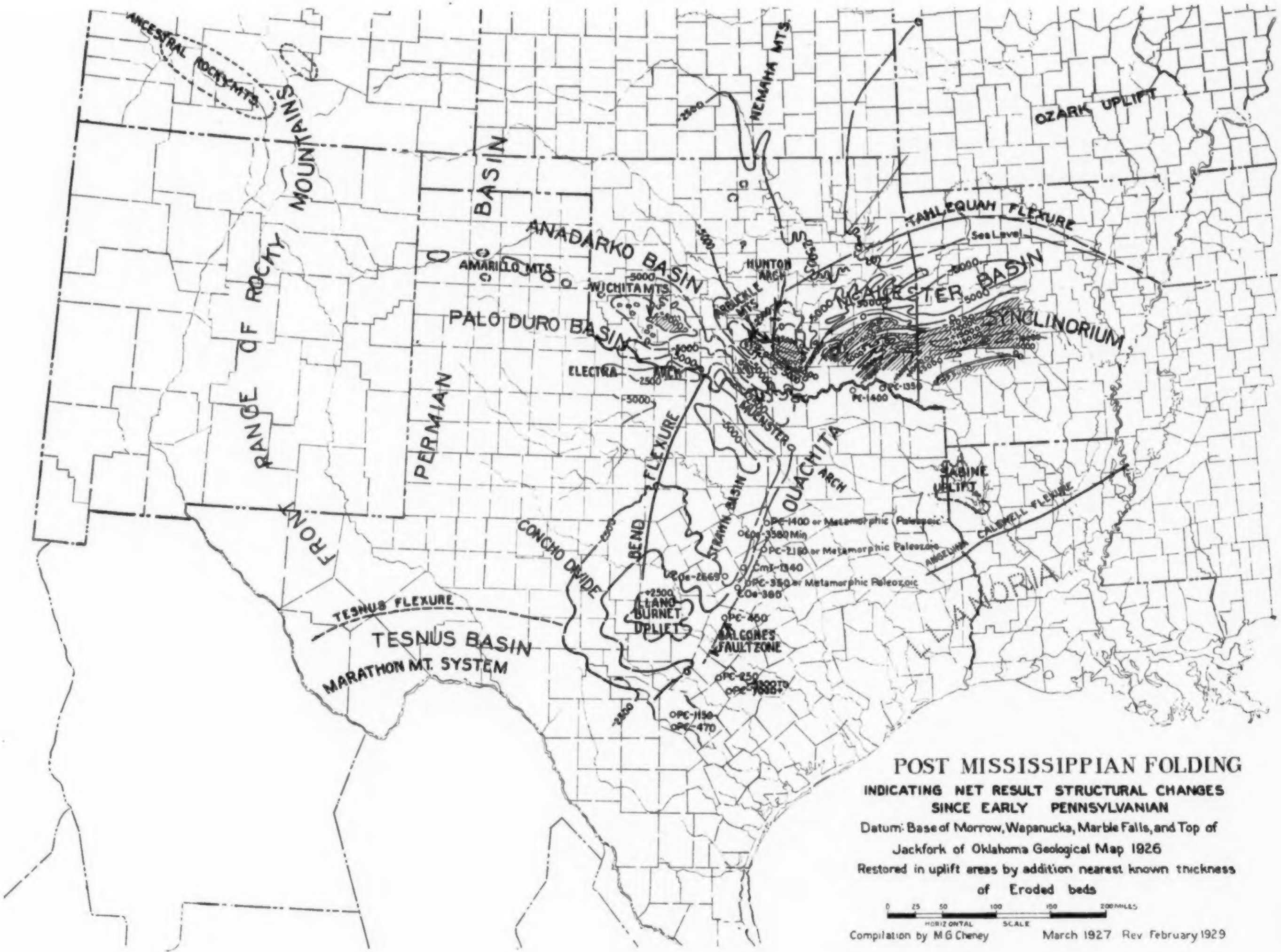
Ouachita areas had taken place. At least some of these faults may be traced by well records below the Pennsylvanian; hence they are not explainable by compaction, buried hills, or other process than structural change due to crustal movement. With thousands of feet of westward tilting in Permian time followed by much eastward tilting, there seems to be no lack of causes for such structural deformation.

STRUCTURAL STUDIES

The familiar question, "What shall a man believe?" is especially applicable to the subject of geologic structure. That such wide varieties of opinion are held upon this subject is sufficient evidence of its complexity. The following remarks concerning structure have been derived mainly from study of Mid-Continent features, and are submitted without pretense of finality.

As stated earlier, structural effects are cumulative; they may be obscured, but not destroyed. Figure 7 is submitted as showing approximately the algebraic sum or net result of structural changes in the Mid-Continent area since early Pennsylvanian time. The predominance of the Ouachita influence is apparent and the intersecting Arbuckle-Wichita trend of pronounced uplift is very noteworthy. However, it is believed that the influence of the Ozark and Llano-Burnet areas has been greatly over-emphasized, for their structural prominence seems to be due almost entirely to stability. These areas have persistently maintained a position near sea level while extensive subsidences occurred in the surrounding areas. Their flanks now exhibit a nearly uniform rate of dip in any given direction. Broad continental elevations and tiltings and erosion have led to the exposure of pre-Carboniferous beds. However, in so far as the Carboniferous beds are concerned, these areas must be considered as having been impotent as sources of pressures which might cause folding and, in fact, as having themselves experienced the least structural movement of any part of the Mid-Continent region.

Much of the continental elevation and tilting just referred to has come in post-Jurassic times, as is shown approximately in Figure 8. The extent of these continental movements is best shown in Texas, where the pre-Comanche surface is now ½ mile above sea level in the Permian basin area but 1 mile below sea level, as an average, in the metamorphosed zone of east-central Texas, which was undoubtedly undergoing extensive erosion during Permian times.



ANCESTRAL ROCKY MTS
RANGE OF ROCKY MOUNTAINS
FRONT
PERMIAN BASIN
ANADARKO BASIN
AMARILLO MTS
WICHITA MTS
PALO DURO BASIN
ELECTRA ARCH
NEMAHA MTS
HUNTON ARCH
ARBUCKLE MTS
OZARK UPLIFT
TAHLEQUAH FLEXURE
Sea Level
McALESTER BASIN
SYNCLINORIUM
MUENSTER
OUACHITA ARCH
BEND FLEXURE
STRAWN BASIN
CONCHO DIVIDE
LLANO BURNET UPLIFT
BALCONES FAULTZONE
SABINE UPLIFT
ANGELINA CALDWELL FLEXURE
LLANORIA
TESNUS FLEXURE
TESNUS BASIN
MARATHON MT. SYSTEM
POST MISSISSIPPIAN FOLDING
INDICATING NET RESULT STRUCTURAL CHANGES
SINCE EARLY PENNSYLVANIAN
Datum: Base of Morrow, Wapanucka, Marble Falls, and Top of
Jackfork of Oklahoma Geological Map 1926
Restored in uplift areas by addition nearest known thickness
of Eroded beds
HORIZONTAL SCALE
0 25 50 100 150 200 MILES
Compilation by M G Cheney
March 1927 Rev February 1929

FIG. 7

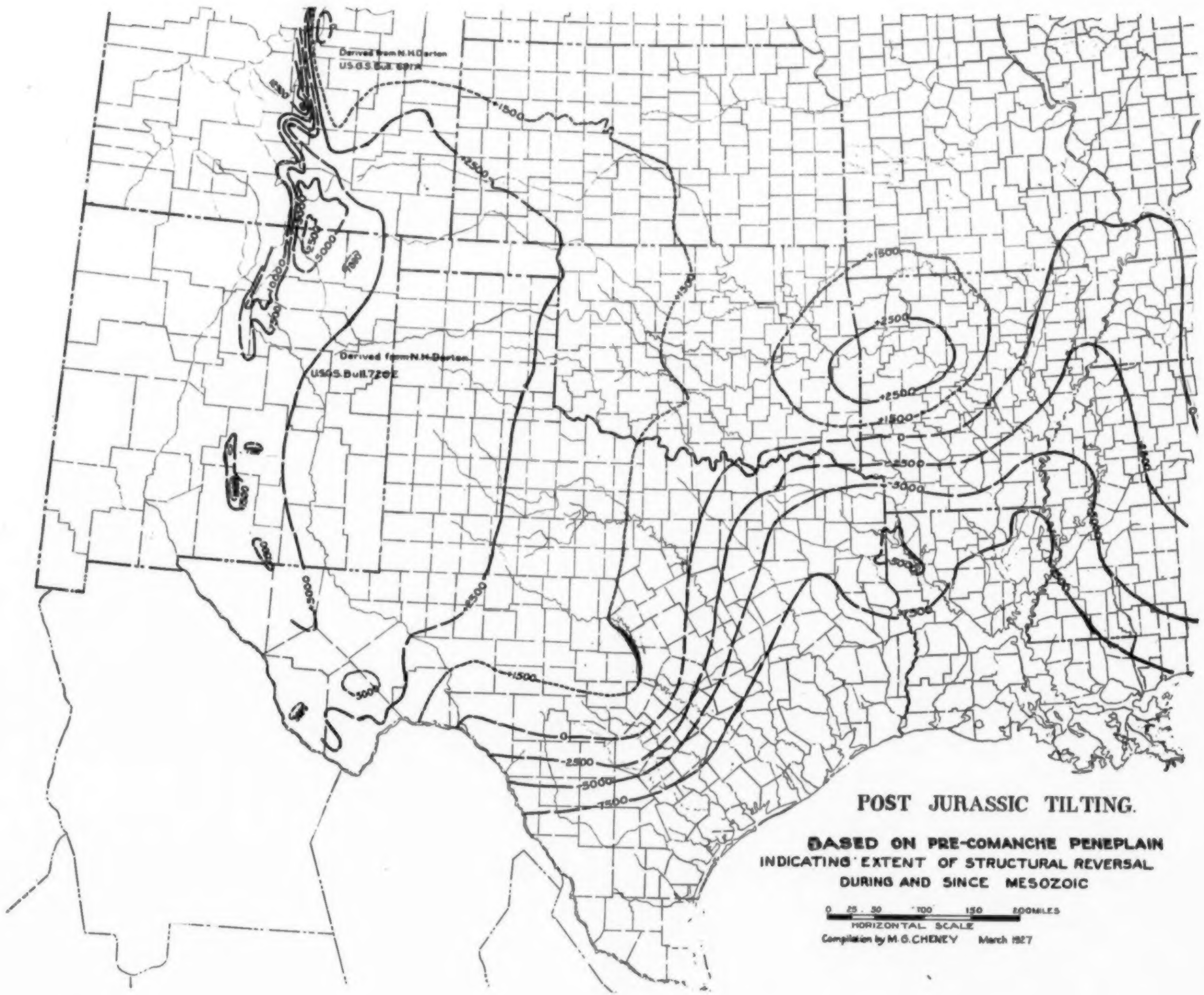

Derived from N.H.Darton
U.S.G.S. Bull. 691A
Derived from N.H.Darton
U.S.G.S. Bull. 720E
POST JURASSIC TILTING.
BASED ON PRE-COMANCHE PENEPLAIN
INDICATING EXTENT OF STRUCTURAL REVERSAL
DURING AND SINCE MESOZOIC
0 25 50 100 150 200 MILES
HORIZONTAL SCALE
Compilation by M.G.CHENEY March 1927

FIG. 8

A classification of structural features observed in these Carboniferous beds is attempted in the following paragraphs and possible causes discussed.

REGIONAL DIPS

As previously discussed, it is believed that the sediments of these shallow epi-continental seas must have been deposited in a nearly horizontal position, but that they have become regionally tilted during the formation of subsequent sedimentary basins and compensating uplifts.

Southeastward dips toward the Ouachita basin must have developed during Mississippian and early Pennsylvanian times. The westward dips now observed in outcropping beds throughout most of the Mid-Continent region are probably results of Permian subsidence on the west and Ouachita uplift on the east. The deeper Permian basins are flanked by the steeper regional dips. Post-Jurassic tilting (Fig. 8) has reduced this westward dip somewhat.

FLEXURES

Areas marginal to a subsiding basin may remain in a nearly horizontal position, or subside at a less rate per mile than the basin proper. The result is of course a flexure where any regional change in rate of dip occurs. Later basins producing nearly opposite tilting may give the flexure the appearance of a geanticline or structural arch without causing any further bending movement, as in the Bend and earlier beds in north-central Texas.

GEANTICLINES—STRUCTURAL ARCHES

Large areas which have been affected by only moderate amounts of elevation, yet show much structural relief due to more or less contemporary subsidence of two main opposed flanking areas, are herein considered geanticlines. All older rocks must be affected by an arched bending movement with much more complicated results than in a flexure. Examples already discussed include the Hunton, Muenster, and Electra arches. A very broad movement of this type might well be termed a "divide," as the Concho divide of central Texas.

UPLIFTS

Large areas which have been only moderately elevated, but which show considerable structural relief due mostly to subsidence of the surrounding areas at various times, may well be termed uplifts, such as the Ozark or Llano-Burnet uplifts.

GEOSYNCLINES—SEDIMENTARY BASINS

The foregoing sedimentary studies disclose ample evidence that these epi-continental deposits accumulated with unequal thickness regionally, and to such great thicknesses that change of sea-level could have been no consequential factor. Sedimentary accumulations of this type are therefore just as convincing evidences of crustal movements as are thousands of feet of uplift and consequent erosion.

Basins may be influenced by physical changes; for example, they may take form initially through thermal contraction following long periods of erosion and cooling and, conversely, may no doubt cease subsiding if thermal expansion in the subsiding rock column progresses more rapidly than tendencies toward subsidence.

As discussed later, it is believed that the formation of deep sedimentary basins leads to crustal weakening, creates an abnormally light zone near the surface, is preparatory, evidently a prerequisite for, and direct cause of, extensive crustal failure and orogeny. The continued subsidence and formation of these deep geosynclines seems to be dependent upon the combined influence of erosion and deposition, or unloading and loading of the earth's crust in contiguous areas.

For many reasons it is as improbable that basins subside evenly as it is that uplifts rise uniformly. Local structural features sufficiently pronounced to control migration and accumulation of oil are taking form during subsidence.

PLAINS TYPE OF FOLDING

Two of the most vexing problems to the Mid-Continent geologist are the interpretation of subsurface structural conditions from investigations of the structural attitude of the exposed beds, and the occurrence and location of sand bodies with reference to structure. The latter seems largely fortuitous, being controlled by several variables such as the prominence of the submarine topography caused by the structure, depth of water, arrival of arenaceous material, and vagaries of distribution by wave and current action. The prediction of subsurface structure from surface mapping is more amenable to reason, provided broad areas have been correctly mapped and the geologic history of the district is understood.

Powers[1] has given the name "Plains type of folding" to the "small irregularly distributed but abundant anticlines periodically rejuvenated" which are characteristic of a large part of the Mid-Continent region.

[1]Sidney Powers, "Structural Geology of the Mid-Continent Region; a Field for Research," *Bull. Geol. Soc. Amer.*, Vol. 26 (1925), pp. 379-92; including important discussion by K. C. Heald.

The theory that these folds were caused mainly by vertical movement was advocated at an early date by Gardner.[1]

Foley[2] has given an excellent review concerning the origin of these folds and points out "very definite evidence that these structures are the result of diastrophism."

The writer believes that the ordinary Plains type of folding must be assigned primarily to crustal deformation rather than to any other influence such as compaction or buried topography. The amount, as well as the fact itself, of rejuvenation commonly noted demands a true structural cause for these features, which differ, mainly in degree, from unquestioned larger folds such as the Arbuckle Mountains.

Numerous local crustal adjustments and repeated rejuvenations seem unavoidable because of the following conditions:

1. The inherent weakness throughout broad areas of a heterogenous crust which has undergone such a great series of changes as are recorded by pre-Carboniferous rocks.

2. The inevitable irregularity of subsidence and uplift caused (a) by these weaknesses, and (b) by variations in subcrustal compression as basin and uplift changes occur. (The sediments penetrated by the drill are measures of former subsidence.)

3. The magnitude, form, number, and shifting location of the basins and uplifts which occurred during and since the Carboniferous require an infinite number of local adjustments to produce such great regional features. There is plentiful evidence of the slow, progressive, oscillatory nature of these changes.

4. Fatigue and yielding in the resistant crust caused by strain or stress would be facilitated by frequent vibrations from earthquakes and by the various tidal influences which affect the earth's crust every day.

Regarding structural interpretation, the purpose of mapping broad areas is: (1) to determine the normal slope and direction of the plane into which these flat beds have been tilted so that folds may be studied with reference to this plane and the amount and location of structural deformation correctly ascertained (the use of sea-level reference in contouring being mostly for convenience); and (2) to permit identification of the main structural trends of the district. Almost invariably these main structural trends as mapped at the surface have been persistently prominent; hence they have continuously affected deposition, as well as

[1] J. H. Gardner, "The Vertical Component in Local Folding," *Bull. Southwestern Assoc. Petrol. Geol.*, Vol. 1 (1917), pp. 107-10.

[2] L. L. Foley, "Origin of Folding in Oklahoma," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 11 (1927), pp. 639-40.

migration and accumulation of oil, as heretofore discussed. Thickening of beds toward the intervening shallow troughs is ordinarily sufficient to make the local features flanking these main axes even less prominent with depth, and such folds are commonly found to have caused only minor, if any, accumulations of oil.

Many larger regional changes incident to major basins and uplifts cause thickening and thinning of beds, thus necessitating consideration in correlations and subsurface interpretations as emphasized by Levorsen.[1]

Structural trends developed during successive periods may vary in direction. The pre-Carboniferous trends seem to have been mainly west-northwest, as already noted. The Ouachita basin and orogeny must have largely controlled structural developments throughout much of the Mid-Continent area during most of the Mississippian and Pennsylvanian epochs, producing northeast trends of folding. The Ardmore basin evidently accentuated the pre-Carboniferous lines of folding within its sphere of influence. Permian basins necessitated adjustments from diverse centers of subsidence, and post-Jurassic embayments and tiltings added further complications.

En échelon folding and faulting may be the natural result of the local features along an older line of weakness being accentuated by potent forces coming from a new direction.

To recapitulate: prediction of subsurface structural conditions requires: (1) correct determination of the local deformations and main structural trends of a district; (2) estimation of the effect of changing thickness of beds; (3) consideration of direction of earlier structural trends; and (4) interpretation of the location and configuration of the buried folds of the particular oil-bearing horizon under consideration, as suggested by the observed deformation in upper beds.

OROGENIC DEFORMATIONS

Lava flows, batholiths, *et cetera*, seem to offer adequate proof of some condition of actual or potential rock fluidity, at varying moderate depths beneath the observed resistant crust. Any local reduction of pressure or strength in the overlying crust must stimulate the tendency for this material to migrate vertically, obliquely upward, or even horizontally, as conditions demand or permit.

Areas within or marginal to deep sedimentary basins would be especially subject to extensive crustal and subcrustal readjustments, for

[1] A. I. Levorsen, "Convergence Studies in the Mid-Continent Region," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 11 (1927), pp. 657-82.

during basin development the resistance of the crust is doubtless reduced by fracturing necessitated by changed position and by linear extension as former plane surfaces take on arcuate form. Heating, resulting from friction and greater depth, would render the lower part of the crust less resistant.

Contemplation of the great sedimentary basins heretofore discussed incites inquiry into the processes by which such great quantities of clastic material can be supplied and received by contiguous areas. Obviously, such extensive contemporaneous movements of uplift and subsidence must be related. Assuming that both areas had rock columns practically normal in mass at the beginning but were standing one slightly above, the other slightly below, sea-level, it seems that the erosion of 10 feet of rock surface from an area 100 miles square would cause crustal lightening amounting to 225,000,000,000 tons in the higher area and the burdening of the crust of the shallow basin by this amount plus additions from oxidation, hydration, and organic increment, so that, unless subcrustal migration occurred, the areas would be out of balance by approximately 500,000,000,000 tons. But under this condition subcrustal material would probably tend to gradually shift from beneath the basin toward the area of reduced pressures. It is probable that erosion and deposition take place somewhat faster above the crust than does this surge of plastic material below; hence, additional losses and gains at the surface increase or at least repeatedly renew the unbalanced condition and additional subcrustal migration ensues. Thus erosion areas may be repeatedly uplifted and basins repeatedly lowered through subcrustal shifting as a result of the work of such natural processes and forces as degradation and gravity. In some such manner as this the necessary space is developed in the basin area and the inconceivably vast quantities of materials are supplied.

The total subcrustal material displaced from beneath the basin must be nearly equal in volume to the incoming sediments, otherwise accumulation could not occur. It is held that by Carboniferous time, the earth's interior was stable and without voids; that thermal expansion would fully offset, perhaps exceed, the volumetric changes in the crust due to compression and chemical recrystallization in the crust caused by added burden. The unequal densities of materials moved above and below the crust results in the anomalous situation that the basin becomes lighter as it sinks and the erosion area heavier as it rises. The following table gives the approximate percentage change in total mass, various conditions being assumed such as larger area of erosion than deposition,

sediments nearly 1 mile thick on both areas at the start, rock densities as indicated in Figure 9, addition of 5 miles of sediment to the basin, and maximum uplift of 2 miles in erosion area.

	Per Cent Mass Decrease Beneath Basin	*Per Cent Mass Increase Beneath Erosion Area*
Upper 5 miles	14.0	3.6
Upper 20 miles	4.4	1.3
Upper 60 miles	1.4	0.5

A certain migratory tendency is likely to affect both areas, for loading may progress, delta-like, and subcrustal displacement may elevate the near side of the erosion area. However, conditions evidently arise or exist which cause excessive accumulation in certain areas. When they do, the damaging exchange is not halted until crustal failure results and vertical movements lower the erosion and elevate the basin areas. Certain trends of weakness which have developed in the crust of the basin area finally fail to restrain upward movement of subcrustal material which must everywhere seek escape from the tremendous pervasive pressures imposed by crustal rocks (more than 100,000 pounds per square inch below the depth of 17 miles). The resulting diastrophic uplift may be wedge-shaped, or a series of sharp wedges. Also a large block or blocks between major trends of weakness may be forced upward, permitting heavier columns of the erosion area to subside. In such areas the crust of the greater part of the basin area remains below sea-level, as great structural troughs.

The amount of orogeny appears to be proportional to the size and depth of the sedimentary basin, so that in areas like the Ouachita basin extensive failure along several lines of weakness may develop, and subcrustal material in large volumes may migrate laterally upward from beneath the heavy erosion area and produce laccoliths or extensive batholiths, which seem to have played a major rôle in four great centers of thrusting in the Appalachian region, according to Keith.[1] A similar development in the Ouachita synclinorium and the Marathon overthrust region may be considered as the fifth and sixth great centers of thrusting of the Appalachian chain. It is interesting to notice that all six of these centers of thrusting have previously been centers of exceedingly thick sedimentary accumulations, and that most of the thrusting seems to have come from the direction of the source of most of the sediments. In such extensive orogeny, the lateral crowding of the lighter upper rock

[1] Arthur Keith, "Outlines of Appalachian Structure," *Bull. Geol. Soc. Amer.*, Vol. 34 (1923), pp. 309-80.

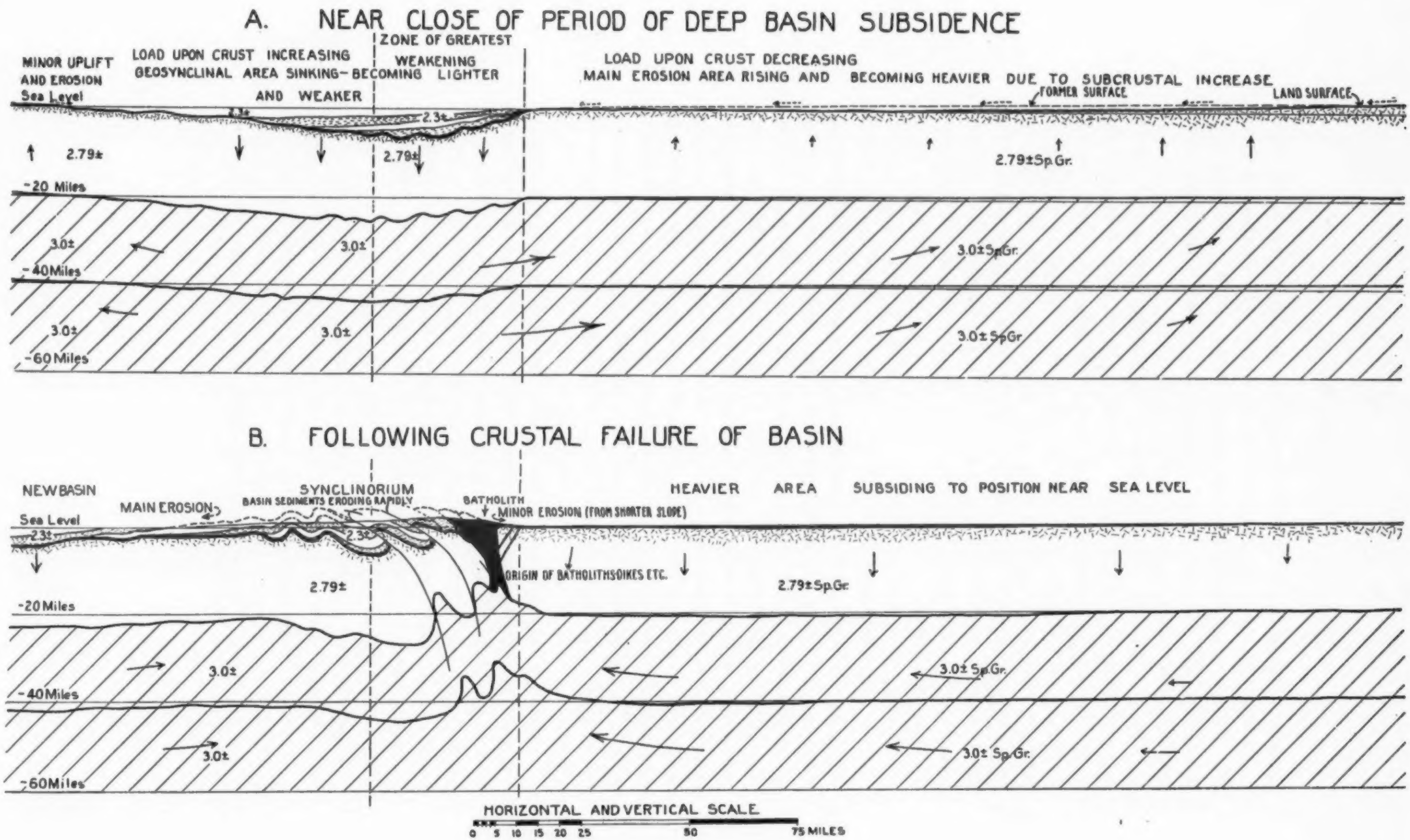

A. NEAR CLOSE OF PERIOD OF DEEP BASIN SUBSIDENCE
MINOR UPLIFT AND EROSION
LOAD UPON CRUST INCREASING
GEOSYNCLINAL AREA SINKING—BECOMING LIGHTER AND WEAKER
ZONE OF GREATEST WEAKENING
LOAD UPON CRUST DECREASING
MAIN EROSION AREA RISING AND BECOMING HEAVIER DUE TO SUBCRUSTAL INCREASE
FORMER SURFACE
LAND SURFACE
Sea Level
2.3±
2.79±
2.79±Sp.Gr.
-20 Miles
3.0±
3.0±Sp.Gr.
-40 Miles
-60 Miles
B. FOLLOWING CRUSTAL FAILURE OF BASIN
NEW BASIN
MAIN EROSION
SYNCLINORIUM
BASIN SEDIMENTS ERODING RAPIDLY
BATHOLITH
MINOR EROSION (FROM SHORTER SLOPE)
HEAVIER AREA SUBSIDING TO POSITION NEAR SEA LEVEL
ORIGIN OF BATHOLITHS DIKES ETC.
HORIZONTAL AND VERTICAL SCALE
0 5 10 15 20 25 50 75 MILES

Fig. 9

masses of the basin area seems inevitable. Overthrusting of one block or fold upon another would tend to force down the under block and permit gradual extensive horizontal displacement of the upper block actuated by subcrustal migrations coming from beneath the crust of the heavier erosion area, as illustrated in Figure 9.

Some subcrustal migration toward the failing basin and from the areas of minor erosion is likely. The ensuing subsidence of these low areas permits their inundation, loading, and subsidence beneath vast quantities of sediments coming from the area of orogeny, which is repeatedly elevated by subcrustal accretions coming mainly from beneath the new basin area. The result is that the area of mountain-building finally resumes a position near sea-level after vast quantities of sediments have been removed from its surface and a rock column of normal density restored to the area.

Co-magnetic regions[1] standing at elevations corresponding approximately with their respective densities, seem to establish the general principle of isostasy, and doubtless this has been true since the beginning of the earth's history. However, since the first acquisition of hydrosphere and atmosphere, there have been these external agencies at work constantly upsetting the normal condition of equilibrium within the lithosphere; and so long as these agencies exist, maintenance of balance in the earth's outer zones seems impossible. Even the most ardent isostasist would, no doubt, hesitate to imply that an area can remain in constant equilibrium during its successive positions as (1) a pre-basin erosion area, (2) a sedimentary basin filled with 5-8 miles of sediments, and (3) a crumpled synclorium elevated thousands of feet above its position as a basin.

Many of the relations herein discussed, such as loading and unloading, geosyncline and geanticline, have long been advocated by proponents of the gravitational theory of orogeny, especially by Herschel and Babbage (1834), James Hall (1859), and C. King (1876), according to Dana.[2] Schuchert's geosynclinal studies are outstanding, and McCoy[3] has made important contributions on these problems in the Mid-Continent region.

[1]Henry S. Washington, "Isostasy and Rock Density," *Bull. Geol. Soc. Amer.*, Vol. 33 (1922), pp. 375-410.

[2]James S. Dana, *Manual of Geology*, American Book Co., Fourth Edition (1895), pp. 380-83.

[3]A. W. McCoy, "Paleogeography and Historical Geology of the Mid-Continent Oil District," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 5 (1921), pp. 541-84.

Existing orogenic mountain areas commonly show only a normal mass beneath their lengthened rock column according to pendulum determinations.[1] They may, therefore, be described fundamentally as great areas of decreased average rock density and crustal failure. The most probable process by which these two conditions may be produced is by the development of deep sedimentary basins forming under the influence of known gravitational processes. It is noteworthy that these deformations are limited in occurrence to the sites and trends of former deep sedimentary basins, and that overthrusting, when present, has come invariably from the direction of greatest erosion; all of which supports the conclusion that areas of deep sedimentary basins do become abnormally light and weak, that erosion areas become abnormally heavy, and that orogenic deformation is caused by excessive unbalancing and weakening of contiguous areas.

CONCLUSION

Successive groups of sediments, studied regionally, disclose a rather complex geologic history in the Mid-Continent region. Such historical studies have many practical applications to the geological problems which confront the petroleum geologist working in this area.

Sedimentary basins afford a very fertile field for study, as they have retained the record of past events, and the formation of local and major folds is largely controlled by them.

The early Carboniferous is characterized by the development of very deeply subsiding sedimentary basins along the southeast parts of the Mid-Continent region; the middle Carboniferous, by extensive orogeny in these same areas of excessive accumulation; and the late Carboniferous, by broad interior basins isolated by various regional uplifts. The Ouachita basin and orogeny stand out as the predominant influences.

These great subsidences which occurred first on the east, later on the west, indicate a surprisingly flexible, yet tenaceous, earth crust, which was influenced evidently from above by transferences of load and from below by great shifts of subcrustal plastic material. A complex series of minor crustal deformations developed throughout the areas of lesser deposition. The areas of great sedimentary accumulations evidently suffered crustal weakening to the point of failure, whereupon their lightened rock columns became affected by great orogenic uplifts. The sequence of developments noticed in this region suggests that the known processes and forces of erosion and gravitation furnish sufficient reasons

[1]William Bowie, "*Isostasy*, E. P. Dutton and Company (New York, 1927).

for the greatest of orogenic movements without resort to theories based upon such unproved events as structural subsidence of oceanic floors or extensive drifting of great continental masses.

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Sincere appreciation and thanks are also hereby expressed to the scores of fellow-workers in the Mid-Continent oil fields for numerous data, ideas, and suggestions.

STRATIGRAPHY AND STRUCTURE OF THE SMOKY HILL CHALK IN WESTERN KANSAS[1]

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ABSTRACT

The general section of the Smoky Hill chalk is described in detail. The key horizons consist of bentonite streaks and hard ledges with definite succession and intervals. The difficulties introduced by the effects of weathering and by the complicated structures are considered. The faulting in the Smoky Hill chalk probably occurred during the Tertiary, and was presumably produced by the adjustment of the brittle "chalk" to deformation and not by compaction. Structure maps based on local dips in the "chalk" are unreliable.

INTRODUCTION

The Smoky Hill chalk lies at the surface through a large area in western Kansas, and within a still larger area it may be reached by core drilling to a depth of 100 or 200 feet. It is evident, therefore, that a knowledge of the character and relations of the key horizons in the Smoky Hill chalk will afford a clue to the regional and local structure of a large part of western Kansas. The stratigraphy of this member can not be properly understood or discussed unless at the same time are considered the effect of weathering on the nature of its component strata, and the peculiar complications introduced by the structural conditions of the region.

Although no general description of the stratigraphy of the Smoky Hill chalk has been published, Bass[3] has described the basal 100 feet of the member in northwestern Trego County, Kansas, and has shown the value of the bentonite streaks and differences in hardness in working out the key horizons. Pinkley and Roth[4] have also described the mineralogy of some of the bentonite beds in Logan County.

[1]Read before the Association at the Fort Worth meeting, March 21, 1929. Manuscript received by the editor, March 7, 1929.

[2]430 Temple Street.

[3]N. W. Bass, "The Geology of Ellis County," *Geol. Survey of Kansas Bull. 11* (1926), pp. 19-23.

[4]G. R. Pinkley and R. Roth, "An Altered Volcanic Ash from the Cretaceous of Western Kansas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 12, No. 10 (October, 1928), pp. 1015-22.

The field work on which this paper is based was done for the Creek Drilling Company in September, October, and November, 1928. The area investigated was chiefly in Logan, Gove, and Trego counties.

STRATIGRAPHY—CRETACEOUS

The Niobrara formation in western Kansas is divided into two members: the Fort Hays limestone below and the Smoky Hill chalk above. The Fort Hays limestone is 50-60 feet thick, and is considerably harder than the upper member. It may be distinguished from the Smoky Hill chalk by the fact that it crops out in beds ranging from 1 to 3 feet in thickness, separated by comparatively thin layers of softer, shaly material; the Smoky Hill chalk is thin-bedded, and the harder layers are much thinner than the softer parts. The Fort Hays limestone also weathers grayish, in contrast to the Smoky Hill chalk, which weathers yellowish.

The term "chalk," applied to the upper division of the Niobrara formation, was evidently suggested by the weathered outcrops of the member. Where unweathered, the greater part consists of light bluish-gray calcareous and chalky shale. During weathering the member assumes a yellowish tint, becomes hard and porous, and in places forms bold and conspicuous cliffs. In Logan County the thickness of the Smoky Hill chalk is known from well logs to be 700 feet, but decreases eastward. The thickness, as shown in the columnar sections in Figure 1, is only 600 feet, probably because the lower part of the member is measured east of Logan County, where it is thinner.

Slight differences in the characteristics of different parts of the member serve to separate it into four different subdivisions. The basal part, 125 feet in thickness, includes the strata below group *B* of the columnar section in Figure 1. It contains two persistent key horizons in addition to its contact with the Fort Hays limestone, and is characterized by many thin bentonite streaks and by thin but persistent hard ledges. The 70-foot interval below group *A* (Fig. 1), contains at several horizons streaks of bentonite and thin, hard ledges that may be used locally as key horizons, though none of these was traced for any great distance. Approximately 70 feet above the base of the member is group *A*, which consists of a group of hard ledges that is very persistent and may be used as a regional key bed. It may be recognized by the fact that it is the most prominent hard group of beds between the top of the Fort Hays limestone and group *B*, by the occurrence of alternating hard and soft strata, and by the absence of bentonite streaks. Approximately

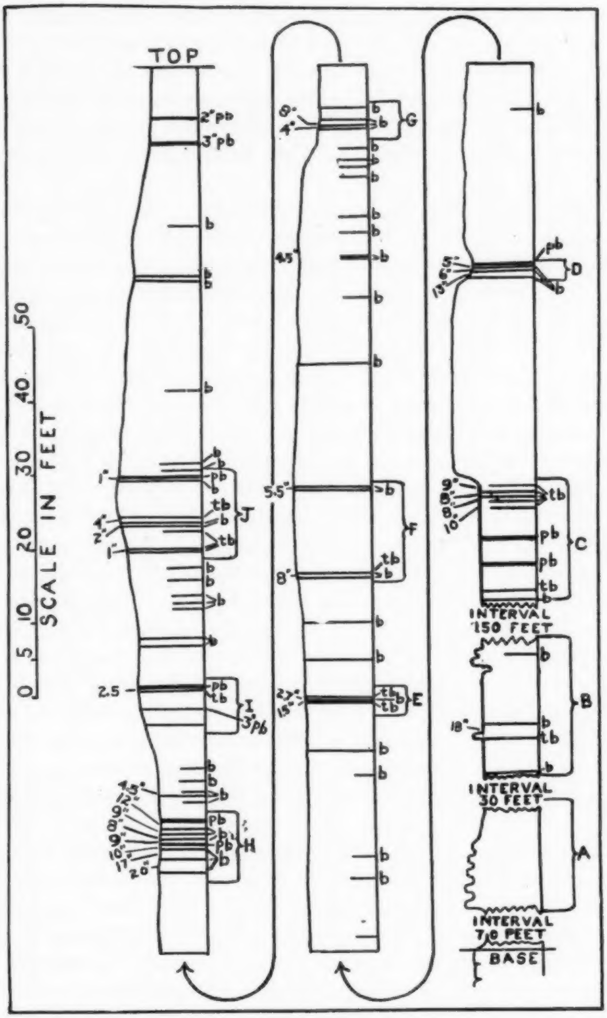

FIG. 1.—Columnar section of the Smoky Hill chalk in western Kansas: *b* denotes bentonite streak, *pb* prominent bentonite streak, and *tb* thin bentonite streak. On the left side of the columns, projections indicate hard beds, indentations soft strata. The figures on the left side of the columns give the interval between the bentonite streaks, and the figures on the right side of the columns give the thickness of the bentonite streaks.

40 feet above group *A* is group *B*, which is the most persistent and easily-recognized key bed observed by the writer in the whole formation. It has been found in Gove, Trego, and Graham counties, and has been traced for more than 50 miles. The hard ledge at the top of the group, with the underlying stratum of soft, dark shale, forms a conspicuous feature, and the thin, hard ledge below forms a white band on the cliffs and shale banks.

Above group *B* is the second subdivision of the member, which is 150 feet in thickness. It consists of soft, thin-bedded calcareous shale, which contains no conspicuous hard ledges. No persistent key horizons were observed in it. There are, however, numerous thin bentonite streaks, and round iron pyrite concretions are especially abundant.

The third subdivision of the member comprises the strata between group *C* and the base of bed *G*, and is 175 feet thick in eastern Logan County and 135 feet thick in eastern Gove County. It is characterized by a calcareous shale which in places weathers to a massive, yellowish-white chalk that forms prominent cliffs and buttes. The strata between groups *C* and *D* characteristically form cliffs and buttes, and the Pyramid Rocks in western Gove County and Castle Rock in eastern Gove County are capped by hard chalk lying just over group *C*. The third subdivision also contains several thin bentonite streaks, some of which form excellent key horizons. Group *C* is easily recognized by its position just below the base of the massive, cliff-making strata, and by the succession of bentonite streaks, as shown in Figure 1. The five thin bentonite streaks shown at the top of the group are everywhere present in eastern Gove and Trego counties, but three of them are missing in central Logan County. The succession of bentonite streaks in group *D* is also persistent and easily recognized. Groups *E* and *F* are less easy to recognize, but are important because they serve to link the upper and lower parts of the member.

The fourth subdivision extends from the base of group *G* to the base of the Pierre shale. It is characterized by many bentonite streaks which are much thicker than in the lower part of the member, and by the brownish-yellow tint of the weathered strata. Group *G* may be recognized by its position just over the top of the massive-weathering beds, and by the succession of the bentonite streaks. It is, however, much less definite and much more difficult to identify than groups *H*, *I*, and *J*. These three groups are persistent and may be easily traced through Logan and Gove counties. The intervals between the bentonite streaks in the uppermost subdivision of the member are somewhat more variable

than in the underlying part. Group *H*, for example, is in some places twice as thick as in others. A remarkable feature is that where these variations in the total thicknesses of the groups occur, the relative thicknesses of the intervals between the bentonite streaks and of the bentonite streaks themselves remain nearly the same. Veinlets of gypsum are very plentiful in the uppermost subdivision of the Smoky Hill chalk, especially between groups *G* and *I*. The part between groups *G* and *I* is soft and easily eroded, but the strata above group *I* weather to a hard, massive chalk that forms prominent cliffs. The chalk in the upper part of group *J* is especially hard and is much quarried for use as a building stone. Weathered surfaces of the chalk in group *J* and for nearly 25 feet above it and 20 feet below it show round holes ranging from $1/5$ to $1/4$ inch in diameter, which are probably worm borings.

Toward the northwest the Smoky Hill chalk is overlain unconformably by the Pierre shale. Though only a few observations on the Pierre shale were made, it is clear that the basal 400 feet of the formation is divisible into five different members, and that the contacts of these members make reliable key horizons. At the base is a soft shale, over which is a hard, fissile shale with septarian concretions, which weathers to a light brownish-gray tint and is in turn overlain by another soft shale. Above this is another hard shale, similar to that below, and on top a soft shale with dark, fossiliferous concretions.

STRATIGRAPHY—TERTIARY

In Trego, Gove, and Logan counties the Smoky Hill chalk is unconformably overlain by the Ogallala formation, of Miocene-Pliocene age. This formation contains fairly reliable key horizons in this region. It consists of sandstones, conglomerates, limestones, and clays. At the base there is in places a cross-bedded pebbly gray sandstone. Nearly 100 feet above the base there is a very persistent hard, thin limestone of peculiar appearance. It is gray or light brownish in color, and contains minute, curved, brownish bands. Its upper surface in places contains minute scars made by roots, and the under surfaces of many fragments are covered by a coating of lime of recent origin or even by minute stalactites. This limestone resembles very closely the caliche deposits of the arid west and was probably formed in the same manner, though it clearly belongs to the Ogallala. Between 10 and 30 feet below the limestone is a bed of rather fine gravel.

Toward the north, in Rawlings, Graham, Phillips, and northern Trego counties, there is in places a series of Tertiary strata which lie

beneath the known Ogallala and which differ in appearance from the typical Ogallala. At the base of these pre-Ogallala strata there is a dense, flinty, pinkish or greenish-gray sandstone, with nodules of greenish chert and plentiful pebbles and grains of pink feldspar. Over this there are greenish-gray or pinkish-gray clays and laminated, fine, white micaceous sandstones. Vertebrate fossils are more plentiful in this series than in the typical Ogallala.

THE EFFECT OF WEATHERING

The stratigraphy of the Smoky Hill chalk can not be properly understood without a consideration of the effect of weathering on the appearance of the different beds, and without a discussion of the difficulties introduced by the complicated structure of the member. Since weathering causes a complete change in the appearance of the beds, it is obvious that if this is not understood much confusion and many mistakes in identification will result.

When unweathered, the greater part of the Smoky Hill chalk consists, as already mentioned, of light bluish-gray calcareous and chalky shale. Certain parts of this shale are lighter colored and more chalky than the remainder. These show as white bands in the banks of unweathered shale, and, because of their greater hardness, tend to make benches in the slopes. As the calcareous shale weathers, it changes to a light yellowish-gray, gray, or yellowish-brown color, and becomes very porous. The softer, less calcareous parts of the member remain rather soft, even when weathered to porous yellow chalk. The lighter, more chalky parts of the shale, however, weather in places to hard chalk that forms the conspicuous buttes and cliffs of the region. The hard, massive chalk is formed only where the conditions of weathering are properly balanced. For example, the buttes and cliffs formed of the hard chalk between groups *C* and *D* are interspersed with stretches several miles in width in which no hard chalk may be seen.

The appearance of the bentonite streaks is also greatly altered by weathering. When unweathered they consist of greenish-gray to grayish-white clay which swells when placed in water. As the rock becomes weathered they change to a rusty brown color, and finally, in the last stages of weathering, they tend to become replaced by veinlets of gypsum or streaks of whitish, powdery, crystalline material. Many of the thin bentonite streaks become obliterated by the effects of weathering.

GENERAL STRUCTURAL CONDITIONS

The complicated structure of the Smoky Hill chalk is the chief obstacle encountered in mapping its stratigraphy and structure. Failure

to make allowance for this factor may result in large errors. The small-scale, complicated structures of the area seem to be connected with the general structure of the region. The Tertiary formations overlying the Smoky Hill chalk indicate the time of formation of these structures, which in turn may explain their origin.

REGIONAL STRUCTURES

The chief regional structural features of western Kansas are the long anticlines which extend approximately north and south, and some of which are steeper on their west flanks. Several anticlines with a general north-south trend are present in Trego, Gove, and Logan counties. The largest of these extends north-northeast from the southwest township of Gove County. Its west flank is much steeper than the east, and west of it there is a fairly sharp syncline. In a few places there are folds with a general east-west trend.

SMALL-SCALE, FAULTED STRUCTURES

The most striking features of the Smoky Hill chalk are the tilted fault blocks which abound in the region where the chalk lies at the surface. With a few minor exceptions, the faults are all normal faults, and are commonly marked by a slickensided calcareous gouge. Most of the faults are small, though the throws of some of them are more than 100 feet. Most of the faults are short, and few of them may be traced for more than a mile. Some of the fault blocks are not tilted appreciably, many are tilted at angles ranging from 5° to 10°, and there are some local dips as steep as 20°. The throws of the faults generally tend to neutralize the rise of the strata due to the dips.

In addition to the fault blocks, there are in the Smoky Hill chalk many small, steep-faulted folds, which range in width from 50 to 1,000 feet. The dips in these minor folds range from 1° to 20°. The faults associated with them are normal faults, which have a tendency to be parallel with the fold. The downthrown side of the fault is generally toward the axis of the minor anticline, indicating tension due to stretching. The fault blocks and small, sharp folds do not occur uniformly throughout the area of the Smoky Hill chalk, but are concentrated in certain areas. These highly faulted and folded areas are generally in structural "lows." That is, the general elevation of the key horizons in these highly disturbed areas is lower than in the surrounding comparatively undisturbed territory. The faulting apparently increases toward the top of the Smoky Hill chalk, and it is also greater in the regions where the structural defoımation due to the main north-south folds is

greatest. For example, the most pronounced major folding in the region is on the west side of the major anticline already mentioned, in western Gove County, and in the steep syncline adjacent on the west, and it is in this same area that the most pronounced faulting occurs.

AGE OF THE FAULTING

In Wallace and Sherman counties, faulting and folding of the same general nature as that already described affect the Ogallala strata and are presumably of post-Pliocene age. In the region farther east, however, the Ogallala strata lie flat across the steep dips in the Smoky Hill chalk and across the major north-south folds, and the faults also stop at the base of the Ogallala. In Phillips County, however, a few observations suggest that the pinkish indurated sandstone already mentioned is affected both by the faulting and by the folding which produced the long north-south anticlines. If this is true, the faulted structures and the folds were formed during the Tertiary, probably during post-Oligocene, pre-Miocene time.

ORIGIN OF THE FAULTED STRUCTURES

It seems to the writer that the faulted structures and small sharp folds were produced by structural forces originating in the earth's crust, and not by differential compaction, as Twenhofel[1] has supposed. This conclusion is supported by the increase in the amount of faulting toward the top of the Smoky Hill chalk, and by the increase in the intensity of faulting where the major folding is most intense. The general type of these small-scale structures is not at all what would be expected to be produced by differential compaction, for the mere settling of the beds could scarcely have produced, in the same key horizon in the same locality, differences of elevation of more than 200 feet, dips of more than 20°, and sharp folds with dips ranging from 5° to 10°, or areas of many square miles in which the strata are cut by a network of faults and generally highly deformed. The subsurface stratigraphy as revealed by well logs gives no support to the compaction hypothesis, for great unconformities such as would be necessary to account for such tremendous compaction seem to be absent. Faulted structures are known to have been formed in post-Ogallala time in parts of western Kansas, and the faulted structures elsewhere may have been formed during the middle Tertiary, after the erosion of the Cretaceous strata above the Niobrara.

[1] W. H. Twenhofel, "Surface Structures in Western Kansas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 9, No. 10 (October, 1925), pp. 1061-71.

The Niobrara may have been deeply buried by younger Cretaceous strata, but since the deposition of the Ogallala and the older Tertiary strata which may exist in the region, the depth of cover has been slight. Hence, the differential compaction would have taken place before the deposition of the Tertiary formations, and any subsequent compaction should be of little importance.

The faulted structures are probably produced by the adjustments of the brittle Niobrara strata to the deformation, particularly to the major north-south folds. Tension due to stretching seems to have been a major factor. The development of the faults seems to have been favored by the fact that the Niobrara is a comparatively rigid unit overlying soft shales, and that it was close to the surface during the deformation.

MEASUREMENTS OF THE INTERVALS

Though it is easy to identify the key horizons in the Smoky Hill chalk and trace them across the country, it is a matter of considerable difficulty to obtain an accurate measurement of the intervals between them. Under ordinary circumstances these intervals could be measured by taking the differences in the general elevation of the horizons, allowing for the known dips, or by drawing structure contours on the different horizons, and observing what interval causes the structure contours on the different horizons to fit together in the most satisfactory manner. These methods can not be used in the region under consideration without serious errors. For example, in T. 14 S., R. 31 W., outcrops of groups *C* and *J* occur intermingled and in many places the outcrops of group *J* are only 50 or 100 feet higher than those of group *C*. Thus the difference in the general elevation of the two groups might easily be supposed to be only 100 feet, whereas the true interval between groups *C* and *J* in this locality is approximately 240 feet. In this manner an error of 140 feet would be introduced into the stratigraphy and into the structure maps.

In order to avoid these errors, the writer determined all the intervals except that between groups *B* and *C* by measuring many stratigraphic sections in the different fault blocks, and gradually fitting them together to make a composite section.

METHODS OF MAPPING STRUCTURE

It is clear that local dips are not trustworthy indications of potential oil and gas structures in this region and that all structure maps based purely on local dips are unreliable. This is indicated by the general

nature of the structures, by the total lack of relation between the steep local dips and the true anticlines, by the fact that the steep dips tend to occur in structural depressions, by the comparison of maps based on elevations on key horizons with maps based on local dips, and by the fact that, as noted by Twenhofel,[1] supposed structures mapped on local dips have been found to be purely imaginary when checked by core drilling.

[1]W. H. Twenhofel, *op. cit.*

LOCAL SUBSIDENCE IN WESTERN KANSAS[1]

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ABSTRACT

The remarkable circular basins of Wallace and Sherman counties, Kansas, have been explained as being due to the collapse of the walls of solution cavities dissolved by artesian waters flowing through the Smoky Hill chalk. Evidence recently gathered by the writer indicates that this theory is untenable, because of the impervious and relatively insoluble nature of the "chalk," and because the solution could take place only at the outcrop. It is concluded that the subsidences are formed by the collapse of the walls of voids produced during the deformation and fracturing of the "chalk."

The peculiar basins of Wallace and Sherman counties, Kansas, are among the most remarkable physiographic features of the country. In some respects these basins resemble the sink holes of limestone regions, but they are underlain by several hundred feet of clay shale, and there are no pure limestones within 800 feet of the surface in the areas where they occur.

In a recent publication Moore suggests that these basins are caused by the collapse of the walls of cavities dissolved by artesian currents flowing through the Smoky Hill chalk. During the course of an investigation of the stratigraphy of the Smoky Hill chalk and of the structure of the area in which the depressions occur, the writer gathered data which indicate that this theory is untenable, and that the basins may have been produced indirectly by faulting or deformation.

NATURE OF THE BASINS

The basins formed by subsidence show an erosion cycle that corresponds with the stages known as youth, maturity, and old age in river valleys. When first formed, the subsided areas have precipitous sides and great depth. According to Moore[3] the subsidence east of Sharon

[1]Read before the Association at the Fort Worth meeting, March 21, 1929. Manuscript received by the editor, March 7, 1929. The investigations in Wallace and Sherman counties were made for the Etnyre Syndicate, and in the other parts of Kansas for the Creek Drilling Company.

[2]430 Temple Street.

[3]Raymond C. Moore, "Note on Subsidence near Sharon Springs, Wallace County, Kansas, *Geol. Survey of Kansas Bull. 11* (1926), p. 96.

Springs, known locally as "The Smoky Basin Cave-in," is 250 feet across and 165 feet deep below the level of the water in the bottom. The level of the water is approximately 75 feet below the east rim of the basin. The walls above the water level are precipitous, and several deep cracks extend into the surrounding formations. A normal fault with a throw of at least 50 feet cuts the north wall of the basin. North of Wallace in the first large draw south of Lake Creek there is a series of basins illustrating the whole erosion cycle. The eastmost subsidence is a steep-walled hole with a deep pool in the bottom. It is reported that this hole was approximately only 10 feet across 20 years ago, and has been gradually enlarging itself since. West of this is a rather steep basin of small area and still further west a broad, gently sloping depression which is much more eroded. On the extreme west is a large, very flat basin which may represent the final stage in the erosion and filling up of the subsided areas. Northwest of Sharon Springs there is another basin, known as "The Old Maid's Pool," which is moderately dissected. Six miles south of Goodland, Sherman County, there are two fairly steep-sided subsidences near the main highway. Broad, flat basins may be observed on the prairies at several localities. These are difficult to differentiate from the basins formed by wind action, which are so common in semiarid regions. It is probable, however, that in this locality some of them are the last stages in the erosion and filling-up of the basins caused by subsidence.

The basins are evidently formed by a series of sudden collapses, rather than by a single collapse or slow subsidence. The "Smoky Basin Cave-in" was formed chiefly by a single sudden subsidence, but it is reported by local parties that there was a small basin there before the main subsidence occurred. After a basin has been formed, it generally becomes partly filled with water from the surface. Meanwhile, it becomes larger, partly because of the erosion and slumping of the sides at the surface, and possibly also because of the enlargement of the area of subsidence from beneath.

ORIGIN OF THE SUBSIDENCE

The subsidence has been explained by Moore[1] as caused by collapse of the walls of caverns formed by the solution of the Smoky Hill chalk. Moore's expression of this theory is as follows:[2]

[1] R. C. Moore, *op. cit.*, p. 96.

[2] *Idem.*

The structural relationships of the Cretaceous rocks show that water entering the Niobrara in eastern Colorado throughout a large area in eastern Colorado northeast of Las Animas may be expected to migrate down the dip of this soluble and more or less porous formation, emerging at the exposures 1,500 feet, or more, nearer sea-level in Logan and other counties farther east in Kansas. It seems evident that the subsidence near Sharon Springs is due to the formation of a cavity of considerable size in the upper part of the chalk, following which, failure of the roof caused the cave-in.

The occurrence of crater-like depressions of varying size at several places in Wallace County under conditions that show clearly a depression of the Cretaceous rocks, the Tertiary being very thin or absent, indicates that solution of the chalk followed by subsidence of the overlying materials has taken place from time to time in the recent geologic history of the region.

It is evident that the subsidence is produced by the collapse of the walls of caverns or voids in the rocks beneath the surface; consequently, it is certain that these rocks are sufficiently rigid to preserve the caverns for a considerable time before they cave in. The problem is to determine the mode of origin of the cavern.

During 1928 the writer gathered evidence which shows that the solution theory advanced by Moore is untenable. A study of the general nature of the Smoky Hill chalk in the area east of the region in which the subsidences occur shows that this member of the Niobrara formation is not sufficiently pervious to permit artesian circulation. The term "chalk," applied to the Smoky Hill member, which comprises approximately 90 per cent of the total thickness of the Niobrara in this region, may suggest a very porous and pervious rock. This is true of the weathered exposures of the member, which are cream-colored or grayish-white, and are both porous and permeable. Where unweathered, however, it consists of a light bluish-gray calcareous or chalky shale, which contains more or less disconnected gray chalky specks embedded in bluish-gray calcareous shale. The unweathered parts of the member appear to be but little more pervious than ordinary clay-shale. This conclusion is substantiatiated by the ground-water conditions of the region. In the areas of outcrop along Smoky Hill River and its tributaries there is not the slightest indication of any water circulation through the unweathered parts of the member. No indication of solution channels could be found, and no springs were observed issuing from the Smoky Hill chalk. Moreover, there are many springs which issue from the contact of the Smoky Hill chalk with the pervious Ogallala and Pleistocene formations. This indicates that the Smoky Hill chalk acts as an impervious barrier to the downward movement of the ground water.

In the vicinity of the outcrops in Gove and Logan counties, wells drilled for water generally fail to find it in the Smoky Hill chalk, as far as could be ascertained. Farther west, where the member is under cover, the Smoky Hill chalk is in part barren of water, though flows of water or showings of gas are found in some horizons. In Yuma County, Colorado,[1] gas is produced from the Niobrara formation. According to the well logs, this gas is produced from a sandstone. It is evident that the Niobrara formation is porous and pervious locally toward the west. The porous and pervious parts seem to be sand lenses, fractures, or possibly lenses of chalk or limestone that are locally porous.

Even if there was artesian circulation through the Smoky Hill chalk, the artesian waters could not have produced caverns like those necessary to account for the subsidences. The formation contains so much shale that it is doubtful if enough of it could dissolve to make caverns. If any quantity did dissolve, the mud produced would probably clog the pores of the rock. Moreover, solution could not take place at any distance from the outcrop. Water can dissolve calcium carbonate only in the presence of carbon dioxide, and the carbon dioxide in the artesian waters as they entered the formation would be speedily consumed to form the solution. As no more carbon dioxide would be added, the waters could dissolve no more calcium carbonate during their entire course through the formation. Further, if the caverns were formed by solution, they would be expected to be filled with water, and when large cave-ins took place this water would be displaced and would be visible at the bottom of the subsided area. Yet when the large subsidence east of Sharon Springs occurred, there was no water visible even in the bottom of the hole.

The key to the origin of the caverns seems to lie in the structure of the region. In Trego, Gove, and Logan counties, east of the area in which the subsidences occur, the Smoky Hill chalk is cut by innumerable faults, and is also thrown into some sharp, faulted folds. These faults and folds were formed before the Ogallala formation was deposited, for this formation lies unconformably over them. In the region in which the subsidences occur, the Ogallala is thrown into small, steep folds and cut by many normal faults. In the Ogallala strata there also occur small, steep, more or less faulted synclines, some of which are only a few hundred feet across and exhibit dips as steep as 20°. The area in which the post-Ogallala deformation of this type occurs corresponds fairly closely with

[1] Kirtley F. Mather, James Gilluly, and Ralph G. Lusk, "Geology and Oil and Gas Prospects of Northeastern Colorado," *U. S. Geol. Survey Bull. 796* (1927), pp. 86, 112.

the general area in which the subsidences are found. As far as could be learned there are no subsidences in the areas in which the Ogallala is undeformed, or only very gently deformed. Since the Ogallala is Miocene-Pliocene, and since the supposed Pleistocene deposits of the region are undeformed, the date of the post-Ogallala deformation was probably late Pliocene or early Pleistocene. The thickness of the Ogallala strata in this region ranges from only 150 to 250 feet, and it is probable that during the deformation of the Ogallala the rocks were buried only a few hundred feet deeper than at present.

The voids or caverns were probably formed during the deformation of the Ogallala formation. The fault surfaces are generally irregular or curved, and as the two sides of the faults moved past each other, voids might be formed where the two sides of the fault did not fit together. The two walls of some of the tensional faults may have been actually pulled apart by the tension. This would be especially probable along the axes of some of the small, sharp folds. During deformation under ordinary conditions, the weight of the overlying rocks is presumably sufficient to prevent the formation of large voids in this manner. In this locality, however, because of the thinness of the overlying strata, and because of the hard, brittle, and relatively rigid character of the Smoky Hill chalk, the walls of the cavities were sufficiently strong to resist the pressures for a considerable time. The absence of the cave-ins in the area in which the deformation occurred in pre-Ogallala time may be ascribed to the earlier date of the deformation. In this region the cover during the pre-Ogallala faulting may have been too great to permit the voids to form, or they may have caved in long ago and been obliterated by erosion.

RÉSUMÉ OF DISCOVERIES AND DEVELOPMENTS IN NORTH-EASTERN TEXAS IN 1928[1]

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ABSTRACT

Operations in northeastern Texas in 1928 were centered principally in the deepest part of the northeastern Texas geosyncline occupied by the interior salt domes.

Boggy Creek salt dome produced 332,000 barrels of oil from eleven wells. The production came from the Woodbine sand flanking the salt dome. This is the first interior salt dome in Texas to produce oil in large quantities.

Anhydrite cap rock or salt was discovered by drilling at shallow depths at East Tyler, Whitehouse, and Oakwood, proving salt-dome formation. These domes had been located during 1927 by the seismograph.

Several wildcats were drilled on known domes and other structures, but in general the year was one of little activity with the exception of Boggy Creek.

The Gulf Production Company obtained a 154-barrel well in a wildcat test in northeast Shelby County.

SALT DOMES PROVED BY DRILLING DURING 1928

East Tyler dome, Smith County, was proved as a salt dome when the Humble's Lassiter No. 1 struck cap rock at 800 and salt at 890 feet. This test was completed April 28, 1928. Later a flank test, the Humble's Williams No. 1, was drilled to 2,719 feet without encountering anhydrite or salt.

Whitehouse dome, Smith County, was added to the list of proved salt domes by the Humble's Van Hovenberg *et al.* No. 1, which found anhydrite cap rock at 487 feet on March 28, 1928. The Humble's Pruett No. 1, a flank test on the same dome, struck the salt at 2,009 feet and penetrated it 8 feet.

Oakwood dome, Freestone and Leon counties, was found to carry salt-dome formation in the Roxana's Marshall No. 1, which drilled anhydrite cap rock from 703 to 807 feet. This test was completed January 23, 1928. The Roxana's Thiele No. 1 was drilled to 3,955 feet on the north flank of the dome without striking cap rock or salt.

These three domes were seismograph discoveries of the previous year.

[1]Read before the Association at the Fort Worth meeting, March 22, 1929. Manuscript received by the editor, March 12, 1929.

[2]Chief geologist, Humphreys Corporation.

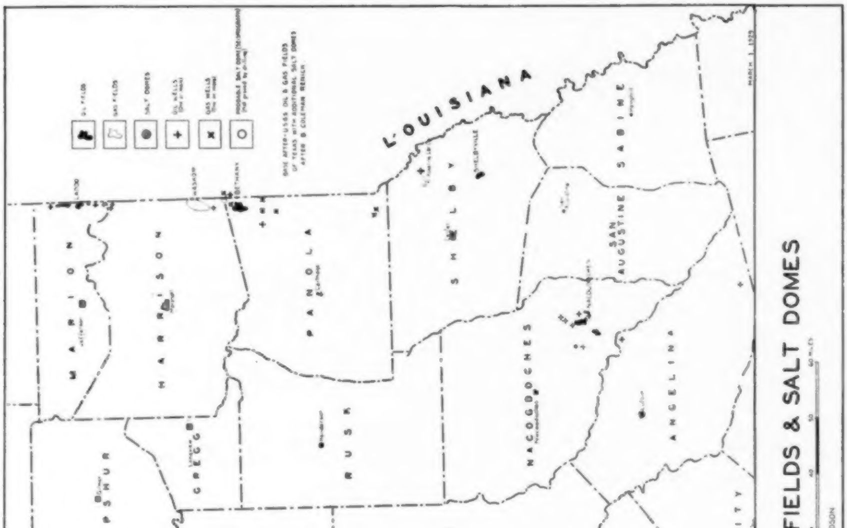

FIG. 1—Northeastern Texas oil and gas fields and salt domes.

SALT DOME DEVELOPMENTS DURING 1928

Boggy Creek salt dome, located in Cherokee and Anderson counties, was the only oil field in northeastern Texas which was extensively developed during 1928. The first commercial well was drilled in 1927, but it was not until 1928 that the Humble Oil and Refining Company entered upon the comprehensive development that resulted in extending the producing area in a narrow zone 2½ miles along the south and east flanks of the salt mass.

Nineteen tests were drilled during the year, of which eleven were producers. The total amount of oil produced during the year was 332,000 barrels, and the daily production at the end of 1928 was slightly more than 2,200 barrels per day.

The Woodbine sand has been the source of all oil produced to date. The average depth of wells ranges from 3,700 to 3,800 feet.

The wells are brought in through small chokes flowing from 100 to 1,500 barrels per day. They should produce, however, considerably larger amounts if opened to full capacity. The initial working pressure varies from approximately 300 to 1,500 pounds per square inch, and practically all wells were still flowing at the end of the year.

The producing wells are located in a narrow zone flanking the salt mass, typical of average Gulf Coast salt-dome flank production except that the producing zone so far developed extends northeast and southwest in a remarkably straight line.

The Humble Pipe Line Company is now caring for the oil from this field by a pipe line running to Groesbeck, Limestone County, where it joins the company's main pipe line to the Gulf coast.

Bullard dome.—Three tests were drilled by the Gulf Production Company on the northwest flank of this dome, extending radially away from the salt. The Gulf Production Company's McCammond No. 1, the test nearest the dome, obtained Austin chalk from 2,625 to 2,800 feet and salt from 2,943 to 2,950 feet. McCammond No. 2 found Austin chalk from 3,079 to 3,233 feet, and Georgetown, from 3,258 to 3,316 feet. McCammond No. 3, located farthest from the salt, found Austin chalk from 3,774 to 4,061 feet, and Georgetown, from 4,205 to 4,219 feet.

Bethel dome.—Two exploratory tests were drilled on this dome. The Pure Oil Company's Cook No. 1 obtained formations as follows:[1]

	Feet
Top Midway	1,380
Top anhydrite	1,490
Salt	1,600
Total depth	1,610

[1]Determinations by The Pure Oil Company Laboratory.

The Pure Oil Company's Bruce No. 2 was still drilling in Navarro at 4,007 feet, after striking a finger of anhydrite and salt from 3,447 to 3,512 feet.

Keechi dome.—Cosden and Company drilled their Adams No. 1 to a depth of 4,000 feet on the west flank of this dome, stopping in the Georgetown formation.

Detailed microscopic determinations are as follows:[1]

	Feet
Wilcox	0- 895
Upper Midway	895-1,710
Lower Midway	1,710-2,012
Navarro	2,012-2,502
Pecan Gap	2,502-2,612
Taylor	2,612-2,875
Brownstown	2,875-3,278
Austin chalk	3,278-3,353
Eagle Ford	3,353-3,582
Woodbine(?) (no sand)	3,582-3,721
Buda	3,721-3,780
Del Rio	3,780-3,831
Georgetown	3,831-4,000

WILDCAT TESTS

Several wildcat tests other than those on salt domes were drilled. Some of them were upon recognized surface folds or faults. Only one area developed new production. The number of tests was small, however, considering the relative size and possibilities of the region. Some of the more important tests follow.

Shelby County.—The Gulf Production Company's Pickering Lumber Company No. 1, located in the northeast corner of the county, 15 miles northeast of Center, produced 4,000,000 cubic feet of gas from a total depth of 3,382 feet. A second well, 3,440 feet deep, flowed initially 154 barrels of 38.5°-gravity oil with 4,000,000 cubic feet of gas. It is believed that the oil and gas come from sandstone of Washita age at a depth ranging from 3,240 to 3,260 feet.

Rusk County.—The Texas Company's Goodwin No. 1, a mile south of Henderson, drilled upon evidence of surface structure, found the top of the Upper Cretaceous at 1,800 feet and was abandoned in the Glen Rose formation of Lower Cretaceous age at 4,998 feet.

Detailed formations[2] are as follows:

[1]Determinations furnished by Paul C. Applin, Cosden and Company.

[2]Determinations by J. C. Miller, The Texas Company.

	Feet
Lower Eocene	0-1,800
Upper Cretaceous—	
Arkadelphia	1,800-2,050
Nacatoch	2,050-2,350
Saratoga	2,350-2,446
Marlbrook	2,446-2,708
Annona chalk	2,708-2,772
Ozan	2,772-2,916
Brownstown	2,916-3,070
Tokio	3,070-3,170
Lower Cretaceous—	
Georgetown	3,170-3,627
Goodland	3,627-4,362
Glen Rose	4,362-4,998

Smith County.—The Amerada Petroleum Corporation's Christian No. 1, located 3 miles east of the Steen dome in Smith County, recorded formations as follows:[1]

	Feet
Top Pecan Gap	3,220
Austin chalk	4,502-4,712
Top Red beds	5,125
Total depth (in Bingen)	5,382

Cherokee County.—Rowan Brothers and Nichols' Sleicher No. 1, 10 miles north of Rusk, crossed a fault of approximately 450 feet throw at 3,731 feet and encountered Austin chalk from 4,104 to 4,292 feet, and Woodbine sand from 4,302 to 4,305 feet, both on the upthrown side. Comparison of the log of this well with those of others near it shows that the upthrown side of the fault is on the south. The fault from its surface trace to the Austin chalk has a dip of approximately 59 degrees.

GEOPHYSICAL EXPLORATION

The rapid seismograph campaign of the previous year, which resulted in the discovery of seven probable salt domes, gradually lessened during the early part of 1928. As far as is generally known, no new salt domes were located by geophysical methods during the year.

FUTURE DEVELOPMENT

Boggy Creek will continue to be developed, no doubt, with resulting increase in oil output. This should stimulate operations on other salt domes, and to some extent on faults and folds, in the general area. The difficult problem of developing oil on salt domes will require the expert

[1]Published by permission of the Amerada Petroleum Corporation. Determinations by The Pure Oil Company Laboratory.

work of the geologist and the geophysicist. Continuation of the broad geologic studies already begun will aid materially in the successful exploration of the faults and folds in northeastern Texas.

CRETACEOUS-EOCENE UNCONFORMITY OF VENEZUELA[1]

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ABSTRACT

In contributions to Venezuelan geology the tendency has been to regard the Tertiary as disconformable on the Cretaceous and as rather closely succeeding it in depositional sequence.

The Eocene-Cretaceous contact is exposed at several localities in western Venezuela. At some of these the relation is one of marked angularity, particularly in the state of Táchira and on the southern flanks of the Andean chain. On the north side of the mountains the relation is more obscure with the exception of the locality near Los Algodones in the northern part of the state of Lara. Here the exposure is very definite, with basal conglomerate of the Eocene resting upon the vertical eroded edges of the Cretaceous.

The Tertiary section from here north is complete, well exposed, and definitely determinate, and the underlying Cretaceous rocks are, in turn, definitely continuous with the Cretacous formations which flank the mountains on their north side.

The unconformity is of such marked discordance that a distinctly unconformable relation between the basal Eocene and the Cretaceous throughout Venezuela is indicated. A very considerable uplift at the close of Cretaceous time with a consequent long period of erosion preceded the deposition of the earliest Eocene sediments.

For reasons that are easily understandable public contributions to the knowledge of the geology of Venezuela have in recent years been rare. Since the days of the early geologic explorers and during the intensive study of recent years, the literature regarding Venezuela has increased slowly and, with one prominent exception, the results of geologic research have been withheld.

In such contributions as have been made, however, the tendency seems to have been to regard the Tertiary as deposited in many places unconformably upon the Cretaceous, but to accept local disconformity with the inference of a general close succession of Tertiary sedimentation at the end of Cretaceous time. These opinions are based upon the coal-bearing nature of the lower Eocene sandstones and shales and their obvious deposition upon a swampy land area near sea-level, upon the fact that the Eocene rests in many places directly on the Upper Cre-

[1]Read before the Association at the Fort Worth meeting, March 23, 1929. Manuscript received by the editor, March 8, 1929.

[2]Consulting geologist, 721 Mayo Building. Introduced by R. A. Liddle.

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taceous formations, and upon the probability of disconformable relations between the Colon shales of the uppermost Cretaceous and the Misoa-Trujillo formation of the basal Eocene in the southwestern part of the district of Perijá. The present theory of Cretaceous-Eocene relationship is admirably summarized by R. A. Liddle.[1] He states that:

> Over all of Venezuela north of the Orinoco receding waters withdrew at the close of the Cretaceous, and the former sea bottom emerged as a low, flat, poorly-drained, undulating plain containing large river deltas. The slight relief of this land area probably was due to disturbances at the close of the Cretaceous....Though this emergence was relatively slight....it was sufficient to terminate with few exceptions a Cretaceous true marine biologic cycle and initiate a fresh and brackish water fauna and flora of Eocene age.

During nine months in 1926-27 the writers had the opportunity, in geologic reconnaissance, to study the Cretaceous-Tertiary unconformity in many places in Venezuela and particularly at one rare and excellent exposure. It is believed that the conclusions based on these observations may be of interest. It is perhaps opportune here to express to R. A. Liddle the appreciation of geologists, particularly those concerned with Venezuela, for his contribution to the literature regarding the geology of that country. That additions will be made in the future is inevitable, but most certainly they may now be made on the basis of a firm foundation of collective fact.

BASAL EOCENE

The Eocene in contact with the Cretaceous is exposed in western Venezuela along the foot of the Sierra de Perijá west of Lake Maracaibo. Also near San Cristobal and Rubio in the state of Táchira, Eocene-Cretaceous contacts may be observed. From Táchira east the Eocene extends along the southern border of the Andean chain and the Coast Range through the Barinitas region, Pao, and Ortiz, to the area south of El Guapo. In northeastern Venezuela, farther east, basal Eocene sandstones lie on Cretaceous rocks in the area between Barcelona and Aragua de Maturin. From Táchira east, north of the Andean chain, Eocene overlies Cretaceous as far as a point south of Onia. In the Lara-Falcon region the Misoa-Trujillo formation of basal Eocene age extends along the boundary of the states of Lara and Zulia and farther east along that of Lara and Falcon, to a point near the town of Churuguara. In general in these areas the lower Eocene lies upon Cretaceous rocks, but notable exceptions exist.

[1] *The Geology of Venezuela* (1928), p. 179.

In the region west of Lake Maracaibo the Eocene-Cretaceous relationship has been described by Liddle.[1] In the northwestern part of the district of Perijá on rios Gé and Palmar (*a*)[2] the Misoa-Trujillo formation lies unconformably on the Colon shales of the Upper Cretaceous. On the south, however, near Caño Buena Esperanza in southwestern Perijá and in the northern part of the district of Colon (*b*) no angular unconformity has yet been found between the Colon shales and the Third Coal horizon of the Misoa-Trujillo formation of the Eocene. The change in type of sedimentation is said to indicate a disconformity if not an unconformity. In southwestern Colon (*c*) Eocene coal-bearing shales lie unconformably on the Colon shales. In this region, therefore, with the exception of the area near Rio Loro, unconformity exists between the Colon shales of the Upper Cretaceous and the basal Eocene sandstones and shales. This unconformity may be of considerable extent on the Rio Catatumbo.

In Táchira, 12 kilometers north of San Cristobal on the road to Colon and at a point called Palo Grande (*d*), light-colored, coal-bearing sandstones and shales correlated with the Third Coal horizon of the Misoa-Trujillo formation lie with distinct unconformity on dark-colored Cretaceous shales with interbedded limestones which may be correlated with the base of the Colon or Guayuta formation. South of San Cristobal near La Palmita (*e*) on the road to Rio Frio and the Llanos, a much lower Cretaceous horizon, composed of black shales and chert and correlated with the Barranquin formation, is in contact with almost vertical basal conglomerate of the Eocene. The Cretaceous shales here are highly contorted and are weathered below the conglomerate. Between Rubio and San Antonio (*f*) less evident but probably unconformable relations exist between Eocene sandstones and Barranquin shales of the Cretaceous.

From Rio Frio in Táchira a ridge of Eocene sandstone extends northeasterly through La Fundacion to La Trampa (*g*). North of La Trampa near Pregonero these sandstones, here coal-bearing and undoubtedly of the Misoa-Trujillo formation, are in faulted contact with red sandstones and shales of the Old Red series of Liddle. On the south they rest unconformably, in strike and in dip, upon identical red sandstones at Raizon (*h*) and north of Banco Lamedero (*i*).

In the state of Mérida south of the Andean chain, Eocene sandstones extend from Libertad to Mucuchachi (*j*) where they lie unconformably

[1]R. A. Liddle, *op. cit.*, pp. 184, 188-93.

[2]Letters refer to localities indicated on Figure 1.

on metamorphic rocks and on red sandstones and shales of the Old Red series. From this point south the section is of extraordinary interest in Venezuelan geology. South of Mucuchachi, in the river of that name, the basal conglomerate of the Old Red series may be observed in contact with metamorphic rocks. Farther south the trail to Santa Barbara ascends Cuesta Lomita and Barro Negro or Alto de Arenal, where the red series overlies dark limestones and shales containing *Productus*, *Fenestrella*, and *Euomphalidae* forms.[1] These Carboniferous limestones are believed to be the first rocks of this age definitely determined in the Venezuelan Andean region, although Woodring[2] has described float from west of Calderas, state of Zamora, containing *Productus*. The Old Red series is thus younger than Carboniferous and older than the Cretaceous Barranquin formation. It is interesting to notice that a similarly unfossiliferous red series, the Jiron group, described by Anderson,[3] in Colombia, where it attains a thickness of 10,000 to 12,000 feet, is tentatively placed in the Lower Cretaceous.

South of the ridges of Carboniferous limestones, the trail descends to thick-bedded light-colored sandstones probably of Eocene age overlying metamorphic rocks in the valley of the Rio Caparo and northwest of Santa Barbara (*k*).

Farther northeast in the state of Zamora, up Santo Domingo River from Barinas and Barinitas, Eocene sandstones and shales are in faulted contact with Cretaceous rocks near Altamira. Dark shales with interbedded sandstones probably of upper Eocene age near Calderas (*l*) are underlain on the north by the upper Eocene limestone described by Woodring[4] and by coarse gray sandstones. The latter succeed in the section granites forming the ranges north of Calderas and, although the contact is not exposed, are believed to rest upon the granitic base. Farther north in the southern part of the state of Trujillo the granite intrusion is in contact with clay and graphite schists seemingly much younger than the ordinary metamorphic rocks of Venezuela. Resting upon these schists, at an altitude of approximately 3,600 meters, is a basal conglomerate composed of schist fragments and overlain by thick, nearly horizontal sandstones. As the Cretaceous limestones and black shales

[1]Peter Christ, unpublished French manuscript (Langenbruck, February 12, 1927). The fossils are deposited in the Basel Museum, Switzerland.

[2]W. P. Woodring, *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 11 (1927), p. 993.

[3]F. M. Anderson, "Original Source of Oil in Colombia, *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 10 (1926), p. 384.

[4]W. P. Woodring, *op. cit.*, Vol. 11 (1927), p. 992.

at Niquitao, a short distance toward the north, are highly folded, there is some possibility that these sandstones are of Eocene age.

In the state of Portuguesa, between Guanare and Biscucuy (*m*), relations regarded as unconformable were observed between the basal Eocene and the Guayuta shales of the Cretaceous. Farther east, near Acarigua, younger sediments conceal the Eocene to Pao. North of east from this point Galeras of Eocene sandstones extend to Ortiz (*n*) and beyond, where Liddle[1] has described unconformity between the Eocene and the Cretaceous. In northeastern Venezuela (*o*) the same author[2] has recognized unconformity between the lower Eocene Aragua sandstone and the Guayuta shales of the Upper Cretaceous.

Thoughout the zone south of the Andes and Coast Ranges, from Táchira east to northeastern Venezuela, there seems to be general unconformity between the Eocene and underlying Cretaceous and older rocks, but north of the Andean chain more obscure conditions exist. At Onia (*p*), south of Lake Maracaibo, the structural relations of the basal Eocene beds to the underlying Colon shales are not described.[3] In the region including Trujillo, eastern Zulia, the central and southern parts of the state of Falcon, and the northern part of the state of Lara, Liddle infers in several places[4] unconformity between the Eocene and Cretaceous, but states[5] that:

> Because of extreme folding and faulting where the Eocene and Cretaceous are in contact, it has to date been impossible to recognize the exact structural relation.

It is, therefore, believed that, in this region of complex structure, an exposure of the unconformity between the basal Eocene and the Cretaceous is of considerable interest.

LOS ALGODONES UNCONFORMITY

The unconformity is exposed in the west wall of a small canyon at Los Algodones, district of Urdaneta, in the northern part of the state of Lara (Figs. 1 and 2). The locality is on a road passable to automobiles from Carora to Coro. After passing the Rio Baragua the road ascends 4 kilometers to a summit 140 meters above the river. Here dark,

[1] R. A. Liddle, *op. cit.*, pp. 311-15.

[2] *Ibid.*, pp. 216-25.

[3] *Ibid.*, p. 196.

[4] *Ibid.*, pp. 183, 205.

[5] *Ibid.*, p. 204.

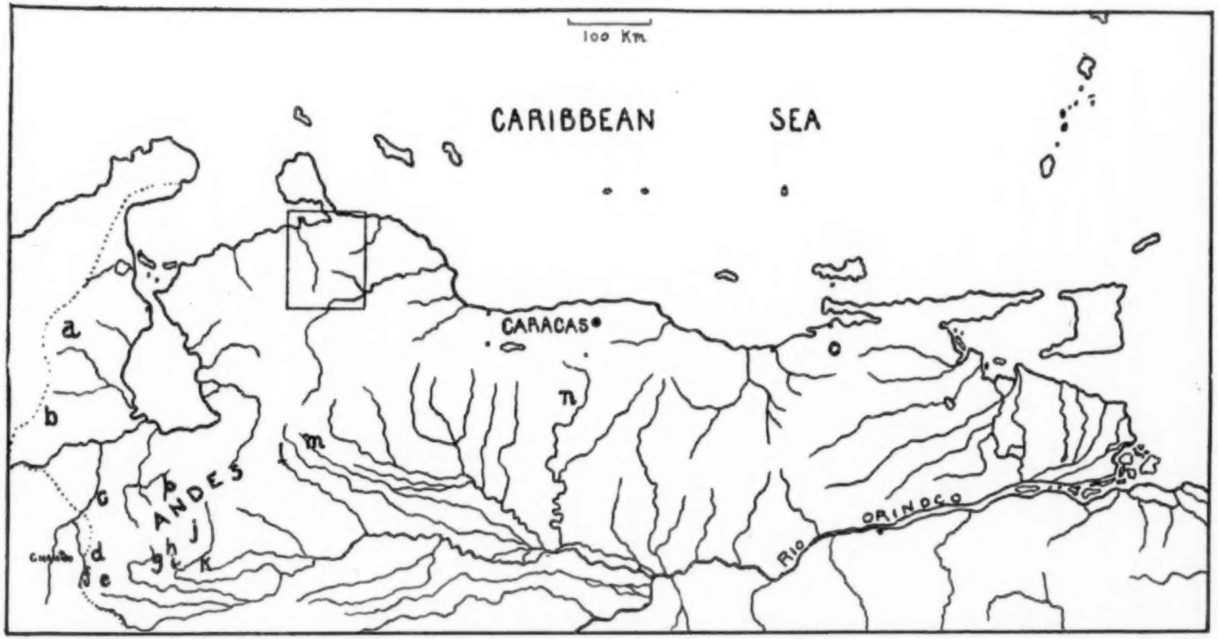

FIG. 1.—Map of northern Venezuela, indicating localities mentioned in text, and area of Figure 2.

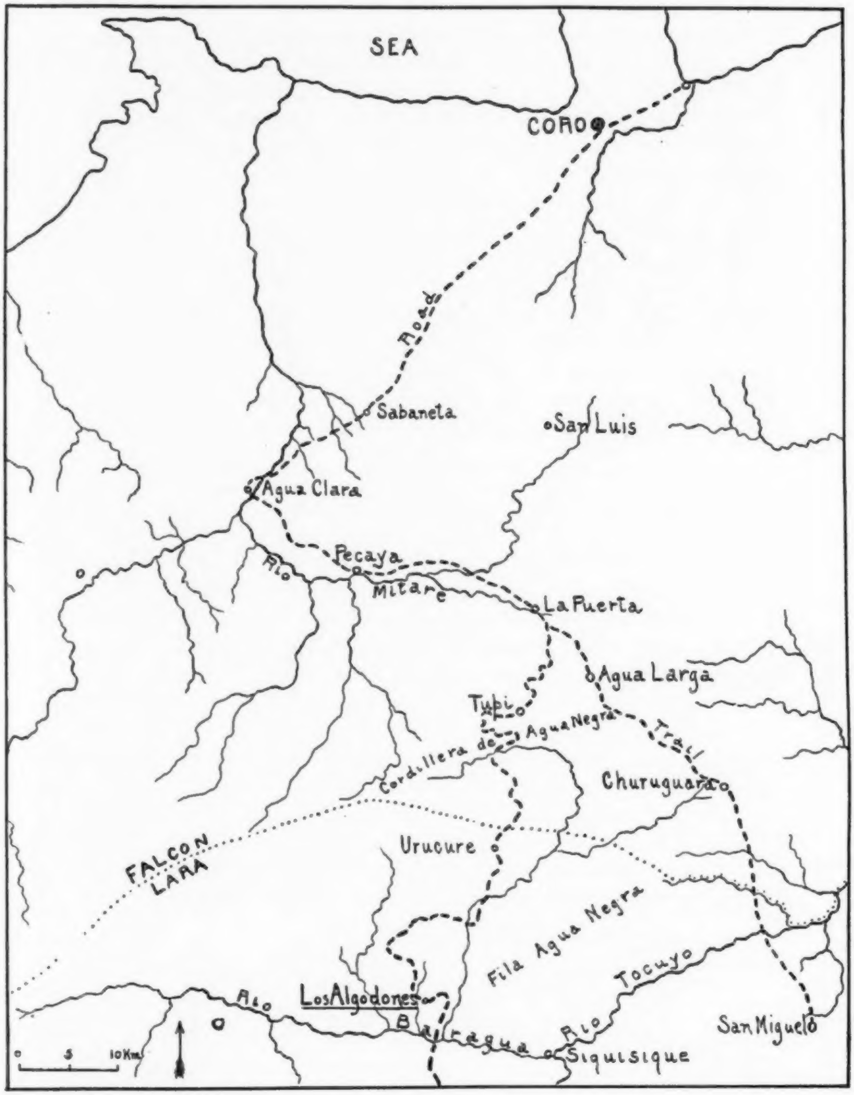

FIG. 2.—Map of northern part of the state of Lara and central part of state of Falcon, Venezuela, showing location of Los Algodones unconformities.

thin-bedded shales with intercalated limestone beds dipping 60° NW. may be seen and traversed 4 kilometers to Los Algodones. These shales with included limestones are definitely of the Guayuta formation of the Upper Cretaceous. Lying upon the Cretaceous rocks at Los Algodones is a thin basal conglomerate with superimposed sandstones, weathered red, dipping 20° N. The relation is definitely one of unconformity (Fig. 3).

The sandstones above the unconformity are correlated with the base of the Misoa-Trujillo formation. They extend with interbedded shale horizons 25 kilometers toward the north across the valley of Churuguara River almost to the summit of Cordillera Agua Negra above Tupi. Here they are overlain by yellow marls and limestones identical with those described by Liddle[1] as of the San Luis formation in this cordillera 12 kilometers toward the east. The absence in the section of the lower Oligocene shales of the Pauji formation is due to the recognized unconformity of the San Luis formation on the Misoa-Trujillo beds[2] in this area.

CONCLUSIONS

The Los Algodones unconformity is of such marked angular discordance that it is believed similar unconformable relations between the Eocene and Cretaceous will be found to exist throughout the Lara-Falcon region. In the Eocene areas described south of the Andean chain and the Coast Ranges from Táchira east to northeastern Venezuela, unconformity of the Tertiary on the Cretaceous or older rocks is general. On the east flank of the Sierra Perijá similar unconformity exists on the north. It would, therefore, seem that with the possible exception of the area near Rio Loro in the northwestern part of the district of Colon and the southwestern part of the district of Perijá, distinctly unconformable relations between the basal Eocene and the Cretaceous exist throughout Venezuela.

The wide extent and the angular magnitude of the unconformity indicate a considerable uplift at the close of Cretaceous time with a consequent long period of erosion before the earliest Eocene sediments were deposited upon low and marshy plains near the Tertiary sea-level.

[1] R. A. Liddle, *op. cit.*, p. 255.

[2] *Ibid.*, p. 253.

FIG. 3.—Photograph of Los Algodones unconformity. Guayuta formation (Upper Cretaceous) below; base of Misoa-Trujillo (Eocene) above.

EN ÉCHELON TENSION FISSURES AND FAULTS[1]

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ABSTRACT

Observations of growing tension fissures reveal that they begin as systems of minute off-set or *en échelon* breaks which subsequently unite to form one continuous, irregular, jagged, tension fissure. It is suggested that the belts of *en échelon* faults of central Oklahoma as well as the Mexia and Balcones fault systems are an expression of incipient *en échelon* tension fissures along whose planes normal adjustment faults occurred.

INTRODUCTION

Twelve years ago Alex W. McCoy[3] suggested that the folds of Osage and adjoining counties in Oklahoma are results of settling, and later he ascribed the cause of the *en échelon* fault systems developed on these structures as an adjustment to tensile stresses caused by the settling of basins. In the latter[4] article he concluded as follows.

> During these times tension faults for adjustment would be started in almost a north-south direction off the granite "highs." At later times, as the basin migrated to the west, sediments of the upper formations would settle down over the faulted areas with marked dips. The settling would adjust itself largely to the granite topography, but faulting would probably be developed primarily in the direction mentioned. It should be understood that faults developing by the process just described would not continue great distances. The maximum extent would probably be only a few miles, and the tendency to "scissor" might be expected. Groups or faulted zones might extend for quite a distance in the direction of faulting, but the faults themselves would be individual and largely disconnected.

Previous to the preceding contribution, Fath[5] ascribed the origin

[1]Read before the Association at the Fort Worth meeting, March 22, 1929. Manuscript received by the editor, February 20, 1929.

[2]Imperial Oil, Ltd.

[3]A. W. McCoy, Discussion, *Bull. Southwestern Assoc. Petrol. Geol.*, Vol. 1 (1917), p. 110.

[4]A. W. McCoy, "A Short Sketch of the Paleogeography and Historical Geology of the Mid-Continent Oil District and Its Importance to Petroleum Geology," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 5, No. 5 (September-October, 1921), pp. 541-44.

[5]A. E. Fath, "The Origin of the Faults, Anticlines, and Buried 'Granite Ridges' of the Northern Part of the Mid-Continent Oil and Gas Field," *U. S. Geol. Survey Prof. Paper 128-C* (1920).

of these folds and faults to a rotational horizontal slipping on the basement rock of the Paleozoic sediments.

Later Foley,[1] on the basis of additional experiments, concluded that

(1) The belts of short, *en échelon*, parallel faults were caused by horizontal movement along shear lines striking about N. 25° E. (2) The noses striking in a northwest direction were caused by shearing stresses along lines about N. 65° W., together with compression forces acting in a northwest-southeast direction. (3) The folds striking in a northeast-southwest direction were caused by compression forces described above. (4) These phenomena are the result of rotational stresses between the Ozark uplift and the granite ridge of Kansas.

Recently Brown[2] concluded, also on the basis of experimental studies, that

The folds of Osage County are believed to be primarily the result of compressive forces acting from all directions.

In a subsequent article[3] he concluded as follows regarding the faults.

Horizontal movement along buried faults may result in the development of shear faults or folds and tension and thrust faults. The folds are greatly elongated and apparently are produced only when the underlying beds are of varying competency.

The most recent contributions to this interesting problem were made by Nevin and Sherrill.[4] The announcement of the publication of their articles was made in the December, 1928, number of this *Bulletin* when a large part of this present article had been written. The completion of this paper, however, was held in abeyance until the writer had an opportunity to study what he anticipated might be similar ideas regarding the cause of the *en échelon* fault systems. After reading the titles of these forthcoming papers the writer of this article felt certain that the views regarding the origin of the *en échelon* faults would be identical with his. However, Sherrill[5] concluded as follows.

[1] Lyndon L. Foley, "The Origin of the Faults in Creek and Osage Counties, Oklahoma," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 10, No. 3 (March, 1926), pp. 293-300.

[2] R. W. Brown, "Origin of the Folds of Osage County, Oklahoma," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 12, No. 5 (May, 1928), pp. 501-13.

[3] *Ibid.*, "Experiments Relating to the Results of Horizontal Faulting," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 12, No. 7 (July, 1928).

[4] C. M. Nevin and R. E. Sherrill, "Studies in Differential Compaction" and "The Nature of Uplifts in North-Central Oklahoma and their Local Expression" and "Origin of the En Échelon Faults in North-Central Oklahoma," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 13, No. 1 (January, 1929), pp. 1-37.

[5] R. E. Sherrill, "Origin of the En Échelon Faults in North-Central Oklahoma," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 13, No. 1 (January, 1929), p. 37.

In general, then, it may be said that the present attitude of the surface formations, in this area, clearly indicates that they have been subjected to torsional stress and that in a part of the region this was accompanied or followed by a steepening of the regional dip in the faulted area. A combination of these stresses will, under proper conditions, form *en échelon* faults trending as do the faults in this area.

These conclusions were, in part, based on experiments performed in which copper-screen wire was coated with cake frosting and subjected to torsional stresses. They were not based upon the experiments on "Studies in Differential Compaction," as the writer had anticipated,—experiments in which, it is believed, a confirmation of the views to be described in this article would have resulted by observation of the nature of the tension fissures which might have developed on the resulting structures, especially in the upper less plastic layers.

Barrell,[1] in a posthumous but timely article, made the following remarks regarding torsion.

> There are certain difficulties in regarding regional joint systems as due to compression and the development of distributive shear, but the difficulties in regarding them as torsional fractures are much greater.

Further on he calls attention to

> a mis-application to nature of Daubrée's experiments with glass plates, which have been cited by many authors.

CASUAL VERSUS CRITICAL OBSERVATIONS

It is believed that the nearest and best known example of conditions similar to, but not identical with, the *en échelon* alignment of the Osage faults is found in the Mexia and Balcones fault systems of Texas. The individual faults in the latter district are evidently longer, but as the off-set conditions are similar, they might have a related origin. Writing of the Mexia and Balcones fault systems, on the basis of experimental studies, Foley[2] says:

> The Balcones and Mexia faulting was due to tensional stresses caused by subsidence in the Gulf coastal region.

He failed, however, to mention the *en échelon* alignment of the faults in his description of them; consequently, he made no attempt to explain this off-set phenomenon. The writer believes he had an excellent oppor-

[1] J. Barrell, "Geological Relations of Earth-Condensation and Resulting Acceleration in Rotation: Part III, On Theoretic Relations to Joint Systems," *Amer. Jour. Science*, Vol. 11 (January, 1926), pp. 34-35.

[2] L. L. Foley, "The Mechanics of the Balcones and Mexia Faulting," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 10, No. 12 (December, 1926), pp. 1261-69.

tunity to study the growth of the experimentally developed tension fissures had they been carefully observed in their initial stages of development. Likewise, what seems to be a clue to the reason for the development of *en échelon* tension faults may be observed on the walls of freshly plastered rooms, newly laid concrete or asphalt highways, sidewalks, linoleum floors, *et cetera*. On all such surfaces may be seen the growth of tension fissures from their incipient stages to complete development (Fig. 1). Since attention is called to this easily accessible field of observation, it is urged that the sequence of events be carefully

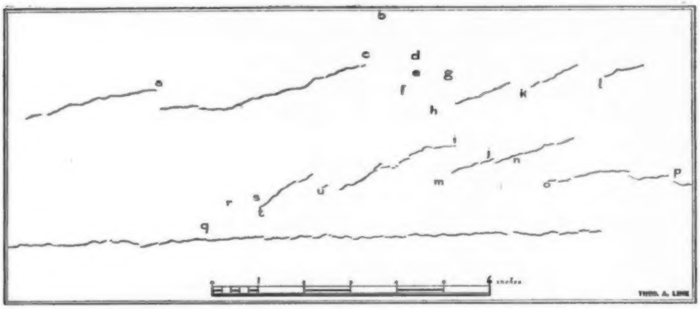


FIG. 1.—*En échelon* and irregular tension fissures on newly plastered wall. Drawing traced directly from wall two months after finishing. (Letters placed for comparison with Figure 2.)

noticed. It will be found that, in such places, where tension fissures are developing slowly enough, the first manifestation is *the appearance of minute off-set fissures in long narrow belts,—a typical en échelon alignment.* If a freshly plastered wall is under scrutiny and the observer returns to make another observation some days or weeks later, it is found that some of these minute off-set fissures have been lengthened so as to accentuate the *en échelon* alignment, and others have been joined to make one large continuous fissure (Fig. 2). A return to the wall a month or so later may reveal the entire system of off-set breaks to be joined in one continuous jagged or irregular tension fissure. On the other hand, another set, also under observation on the same wall, may have the *en echelon* alignment accentuated to a marked degree, seeming to remain thus for an indefinite length of time. In regard to the latter condition it seems logical to conclude that the tensile stresses ceased at the *en échelon* alignment stage and were satisfied or compensated sufficiently to cause no further growth of the fissures. One may also speculate on what the

conditions might be immediately prior to the initial development of the incipient off-set tension fissures. It seems not unreasonable to surmise that if the tensile stresses were so feeble that not even these minute off-set fissures were actually developed, lines of weakness coincident with their loci of potential development might serve later as planes for movements along which subsequent adjustments in the form of normal or compression faults could take place. For lack of a better term applicable to this theoretical stage, "potential *en échelon*" is suggested.

In the completed stage of tension-fissure development many of the incipient off-set breaks are seen to be cut by a longer continuous fissure, resulting in what might be interpreted erroneously as planes of no distortion or shear in the imaginary strain ellipsoid (see *b, d, e, et cetera* in Fig. 2).

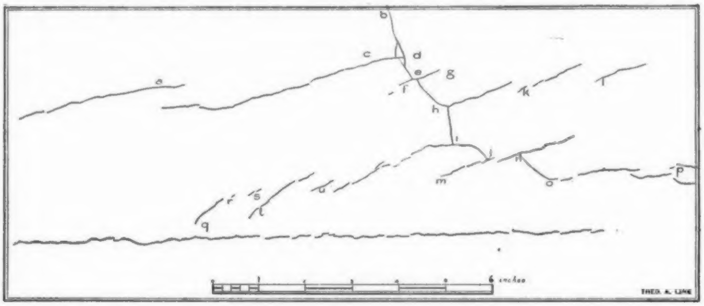


FIG. 2.—Same wall as in Figure 1, showing development of tension fissures three months later. Notice new fissures, in particular one at *b, d, e, h, i, j*, at right angles to the earlier system.

APPLICATIONS OF OBSERVATIONS TO REGIONAL PHENOMENA

Before suggesting a possible origin of the Osage-type faults, the writer wishes to be understood as realizing that *normal* faulting does not necessarily imply *tension*, also that a "*potential tension fissure*" is not *open*, but merely represents a plane of weakness which will be opened if the *tensile* stresses increase; further, that tension may be a force accompanying compression as an adjustment feature.

A lengthy description of the geological setting of the domes, terraces, and faults in north-central Oklahoma is unnecessary. This has been given repeatedly in the cited papers. What seem to be the salient structural and stratigraphic features will be enumerated as working principles.

SALIENT FEATURES OF OSAGE STRUCTURES AND THEIR SIGNIFICANCE

1. The Osage folds are minor structural features whose dips are measured in feet per mile rather than in degrees.

2. There is a preponderance of almost circular or oval domes and corresponding basins, although structural terraces and "noses" are common.

3. At depth, the dip of the folds increases so that directly above the basement complex the dips are greatest in a given fold.

4. On these folds are normal faults whose displacement is relatively small. The individual faults are oriented approximately N. 30° W. in belts or *en échelon* systems which have a general trend of N. 25° E.

Inasmuch as the Osage folds are of such low magnitude that their dips are scarcely discernible to the eye, and as the accompanying faults are of almost negligible throw, it must be concluded that relatively *minute* or feeble forces gave rise to them, or, rather, they seem to be merely the result of *incipient* forces which were arrested before full development. Cross sections of Osage folds, plotted so that the vertical scale equals the horizontal, are quite disappointing. Structure-contour maps of these folds are very deceiving, and it is emphasized that any cross section, here or elsewhere, in which the vertical exceeds the horizontal scale, is not a true picture of actual conditions. The same applies to laboratory experiments simulating Osage folds wherein an artificially produced dome or anticline, whose dips are measurable in degrees, is not a true

Fig. 3.—*En échelon* tension fissures developed on asphalt-concrete pavement built 15 years ago. Age of fissures is probably 13 years. Snow in fissures.

reproduction of an Osage-type fold. Therefore, when applying this mode of attack, cognizance of this fact must be taken.

The faults are essentially all normal, which may or may not imply, but suggests, tension. Further, they are aligned in *en echelon* belts or systems, suggesting rotational compression and shearing. These are not necessarily their cause. however, as pointed out by Nevin and Sherrill. Since the faults, like the folds, indicate results of minor or incipient forces, it seems logical to study, if possible, the results of incipient or minute forces. With very little promise of success in simulating the folds experimentally by compressive forces, the next best attack is on the faults. This was unknowingly, or rather unintentionally, made while performing numerous experiments which have recently been described by the writer in the pages of this *Bulletin* as well as in the *Journal of Geology*.

EXPERIMENTAL EVIDENCE

Tension fissures were actually observed from their initial manifestation to completion on scores of experimentally developed domes and anticlines. Their growth was caused in several different ways. Circular domes were produced by the intrusion of rigid, semi-plastic and fluid materials from below. On top of these artificial structures tension fissures invariably developed and were observed from their inception as minute *en échelon* breaks to ultimate, irregular, ragged, open tension cracks along which many displacements were observable. This sequence of development was observable irrespective of the method or manner in which tension fissures were produced. It is quite obvious that domes or anticlines could also be formed by reversing the conditions of *active*[1] and *passive*[1] stresses; that is, instead of intruding materials from below, resulting in vertical stresses causing growth of a dome or anticline, the method of differential settling and compacting around and over a rigid body, as used by Nevin and Sherrill,[2] would give very similar results. On top of structures developed in this manner incipient tension fissures might be expected because of stretching of the beds by vertical stresses. In the latter condition gravity is the active force and the buried ridges of hilltops the passive resistance. A suggestion as to how this could be verified is in place here, and the writer hopes that someone will have time to perform the experiments as suggested herewith.

Use the same artificial stratigraphic combination employed by Nevin and Sherrill as well as the same sort of underlying artificial ridge, but construct

[1]Although these terms are not very appropriate, the writer feels certain that the reader readily understands their meaning as here used.

[2]*Op. cit.*

the apparatus so that a considerable length is incorporated (as in Figure 4). Before adding the shot, as overburden, deposit a thin layer of plaster of Paris as the uppermost stratum. On top of this place either a piece of blotting or tissue paper; then carefully add the overburden of heavy shot. After the differential compacting has taken place, remove first the overburden, then the blotting or tissue paper *very carefully*. If the compacting has not reached an extreme degree the writer feels certain that minute *en échelon* tension fissures will be in evidence on the crest of the resulting structure. If a sharp structure was produced a continuous, irregular, or jagged tension fissure should result. The latter condition would not be applicable to north-central Oklahoma structures because the dips, as observed in this region, are not measurable in degrees.

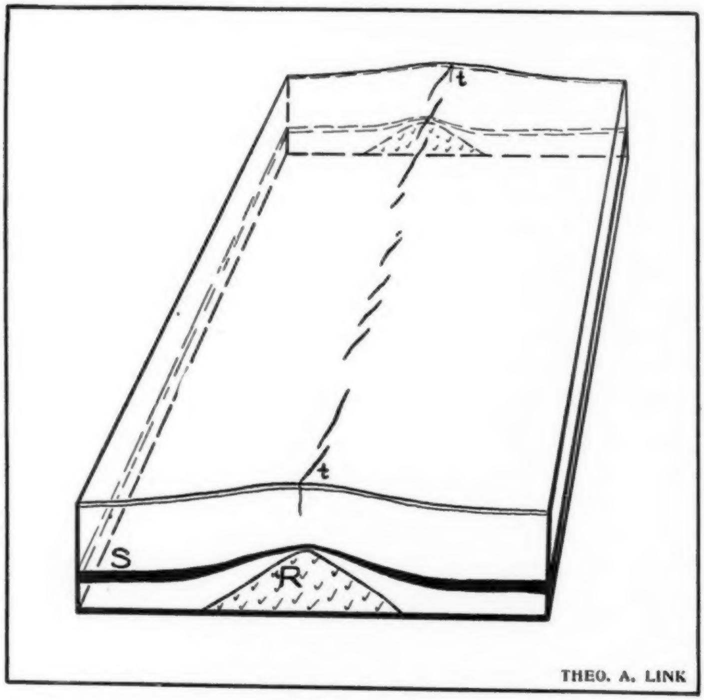


FIG. 4.—Block-diagram illustrating writer's conception applied to Nevin and Sherrill's Figure 7, Plate 3, *op. cit.* Differential settling of sediments (*S*) gives rise to a low arch and a system of *en échelon* tension fissures (*t*). *R* represents a buried ridge.

Regarding this same subject Leith[1] writes:

> When rocks and other hard substances are broken by tension in the laboratory, or when a cement road or sidewalk cracks by tension, the break is likely to be along curved, or even jagged surfaces. It is difficult to secure clean, plane surfaces of fracture extending for considerable distances; yet in the field most joints, which might be ascribed to tension, show these clean breaks along plane surfaces. Even in heterogeneous material, such as conglomerate, it is not usual to see a clean, plane, open joint cutting indiscriminately across pebbles and matrix. If pulled apart by a tension one would expect to find projecting surfaces of pebbles. Unless there is some factor in the situation which we do not yet understand, one can not but suspect that in these cases the joint or plane of weakness was formed by compressive shear, and that tension has merely opened up this structure. Yet it does not do to assume that all joints with clean, plane surfaces are necessarily formed originally by compressive shear, and that tension must be assigned only to jagged, irregular openings; it is known, for instance, that the formation of joints in cooling igneous rocks, as in the case of basaltic parting, develops, at least locally, smooth, plane surfaces. Fine-grained, homogeneous textures may be supposed to be more susceptible to clean breaks along plane surfaces than coarse, heterogeneous textures.

As already pointed out, careful observation of newly laid cement sidewalks and highways and freshly plastered walls has verified the experimental observations, since the first manifestation of cracks due to contraction is the development of belts of extremely minute *en échelon* tension fissures. Examples of such systems of *en échelon* fissures are shown in Figures 1, 2, and 3. With continued contraction the minute off-set fissures ordinarily join one another and ultimately develop into one continuous, jagged, open tension fissure. The *en échelon* alignment must, consequently, be regarded as the *incipient* manifestation of what may later on become a much larger development of a tensional phenomenon. If tension stresses are arrested at this early stage, obviously the *en échelon* system remains as such and concomitant or later movements along the planes may give rise to normal or reverse faulting. Whether such fault movements are due to compressive forces within the tension system of stresses or merely slight adjustments, has no bearing on the original cause of the *en échelon* alignment. Also, the original cause for the tension may have been local tangential compressive forces developing an arch, a dome, or anticline, or the cause may have been differential settling of less competent sedimentary rocks over buried resistant ridges or hilltops.

[1] C. K. Leith, *Structural Geology*. Henry Holt & Company (New York), 1923, p. 52.

BEHAVIOR OF DIFFERENT MATERIALS

A few remarks regarding the nature of materials which display the incipient *en echelon* development of tension fissures are appropriate here. Observations have revealed that very brittle materials like glass, which develop tension fissures with great rapidity, rarely display an incipient *en échelon* alignment. Contraction of ice, on a pond or lake during a very cold winter day, is commonly manifested by a thunder-like noise caused by an almost instantaneous development of a crack or tension fissure. Observation shows that although the crack in the ice is jagged, the *en échelon* phenomenon is ordinarily lacking. The incipient development stage of a fissure in ice or glass occurs during a fraction of a second, and its former existence is manifested only by the irregular and jagged trend of the ultimate fissure. The other extreme is material like asphalt or a mixture of concrete and asphalt such as is used extensively on our modern highways. Innumerable observations of tension fissures, cutting across such highways, have revealed that the incipient *en échelon* stage spreads over a period of months or even years (Fig. 3). Pure concrete pavements also strikingly display the incipient stage.

In the stratigraphic column one would not look for a formation which would respond to tension as suddenly as ice or glass, except possibly solid chert formations and some volcanic glasses such as obsidian. Limestones and sandstones should act very similarly to concrete, and shales might respond somewhat like a combination of concrete and asphalt.

Since the Paleozoic stratigraphic column of north-central Oklahoma is predominantly shale with intercalated limestone and sandstone members, it would be expected that feeble tensile stresses would be manifested by the *potential* and *incipient en echelon* alignment of tension fissures.

The depth at which open tension fissures may develop in the earth's crust is a matter upon which there is no accepted agreement among geologists. The writer has observed *open* tension fissures in Paleozoic limestones in the Rocky Mountains, and in several places deep in the section found small groups of *en échelon* tension fissures in these limestones. Objection might be made on the ground that these fissures were opened after the limestone was exposed to the surface by denudation. In reply to this it is of interest to note that recently a diamond-drill core, taken from one of the Turner Valley wells at a depth of almost 2,000 feet, showed a small anticline on whose crest were undeniably *open* transverse tension fissures approximately 2 millimeters wide.

An examination of the north-central Oklahoma faults suggests that most of them are the result of incipient, or potential, *en échelon* tension fissures, along which normal adjustment faulting resulted. The fault system in Hughes County seems to be an example of a more advanced stage of the tensile stresses before the faulting occurred. Here the incipient, or potential, *en échelon* breaks were cut by a longer continuous fissure.

Whether or not the adjustment movement, by normal faulting, resulted concurrently with the development of the fissures or a little later can not definitely be stated. In the opinion of the writer, however, it seems more probable that the displacements began with the fissuring and in some places even along mere "potential *en echelon* planes" of weakness.

CONCLUSION

It may be concluded that if the existence of a pre-Paleozoic or pre-Pennsylvanian topography, consisting of a series of hogbacks, or cuestas, striking approximately N. 25° E., as well as irregularly-spaced knobs or hilltops, can be established, the differential settling of later sediments over and around these buried features could give rise to feeble tensile stresses, causing the development of incipient *en échelon* fissures along which would occur adjustment by normal faulting. Furthermore, later, but very feeble, local compressive forces may also have been operative and accentuated the lines of weakness already developed. This simple explanation, which is essentially the same as the one put forth by McCoy years ago, appeals to the writer as more acceptable than recourse to torsion or a complicated system of rotational compressive shearing or horizontal movement along buried faults. Furthermore, it is in no way related to the phenomenon of *en échelon folds* previously described by the writer.[1]

DISCUSSION

Lyndon L. Foley, Tulsa, Oklahoma: The tension fissures observed by Link in walls, pavements, *et cetera,* are hardly comparable with most of the tension fissures observed in the rocks of the earth's crust. The rocks which we now observe were buried at considerable depths at the time these fissures were formed. The shearing stresses due to vertical compression will modify the conditions of simple tension, forming fractures whose strike is perpendicular to

[1]Theodore A. Link, "En Échelon Folds and Arcuate Mountains," *Jour. Geol.,* Vol. 36, No. 6 (1928), pp. 526-38.

the direction of tension and dip at angles of approximately 45°. This point was discussed in my paper on "Mechanics of the Balcones and Mexia Faulting."[1]

The *en échelon* faults of Oklahoma and the faults of the Balcones system are not similar, as Mr. Link suggests. The faults of Oklahoma occur in long, straight zones; those of the Balcones system occur in long zones, curving around the flank of the Llano uplift. The faults of the Oklahoma system strike at angles of approximately 45° to the trend of the fault zones; those of the Balcones system are practically parallel with the strike of the fault zones. The individual faults of the Oklahoma system are rather short; those of the Balcones system are much longer in lateral extent. There is considerably more folding in the rocks affected by the Oklahoma faulting than in those affected by the Balcones faulting. The faults in the south end of the Mexia field and in the Luling field are reported to be forked, which is characteristic of the fractures shown in my paper on the Balcones faulting; the fracture patterns of the Oklahoma fault systems resemble the fractures produced experimentally and described in my paper on "The Origin of the Faults in Creek and Osage Counties, Oklahoma."[2] The structure of the Balcones region is characteristic of regional warping, but the structure of north-central Oklahoma is characteristic of regional deformation by tangential stresses of a rotational nature. The faults of these two systems are dissimilar in many important characteristics, the mechanics of formation of the two types of fracture patterns are different, the structural histories of the two regions differ, and the two fault systems can not be considered to have the same or similar origins.

The experiments of Nevin and Sherrill, to which Mr. Link refers, seem to indicate that differential settling might cause considerable folding. Their experiments leave out of consideration a very important factor which would change their results considerably. I believe their conclusions regarding the importance of differential settling are erroneous, and am preparing a discussion of their papers which I hope to publish very soon.

Frederic H. Lahee, Dallas, Texas: If I understand Mr. Link rightly, he attributes the *en échelon arrangement* of faults, observed in Oklahoma, Texas, and elsewhere, to incipient fracturing due to tension, such fracturing perhaps later controlling the position of continued or repeated slipping which may develop on a major scale. He wants to ascribe this initial pattern of fracturing to tension, and not to torsion or compression.

I am a very poor physicist, but I have thought that torsion involved forces of tension and of compression, and that ordinarily one of these sets of forces would be dominant. Either tension or compression might prevail under different circumstances.

In the Mexia zone of faulting, where the displacements range from 250 to more than 600 feet, the faults are normal, but, as far as our data indicate, they are associated with anticlinal folding in a very significant manner. The faults have an average dip of 45°-50° toward the west. The anticlinal fold has its

[1] *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 10 (1926), pp. 1261-69.

[2] *Ibid.*, pp. 293-303.

axis essentially parallel with the fault, and, in successively lower formations, from the surface to a depth of at least 3,000 feet, the axis remains nearly the same distance east of, and close to, the fault in the particular formation. That is to say, the axial plane of the fold is essentially parallel with, and not far east of, the fault. As I have pointed out elsewhere,[1] I believe that this relation is good evidence that the fold and the fault, in each place, were associated in origin. The normal fault suggests tension and the fold suggests compression. Are not these features suggestive of torsion as the kind of stress involved in the development of the faulting in East Texas? But here I believe we must concede that the pattern of the faulting is a major phenomenon.

Personally, I can not conceive of conditions so simple in the earth's crust that tension alone could operate in anything but the most limited areas. Torsion would affect almost all strata subjected to upfolding or downfolding.

C. M. NEVIN, Ithaca, New York: Although the author has, no doubt, plenty of precedent for making no causal distinction between joints and faults, I personally think they should be carefully separated. Indeed, there is no necessary relation between joints and faults—a fault is not a joint along which appreciable displacement has occurred, nor is a joint an incipient fault. Unfortunately joints and faults have been used interchangeably, with a consequent muddling of the issue.

The outstanding characteristic of the *en échelon* faults in north-central Oklahoma is their relation to the regional dip. Wherever the strike of the regional dip changes, the strike of the *en échelon* fault belts makes a corresponding swing This relation is so well established that there seemingly must be a connection between the stress that caused the regional dip and the stresses that caused the *en échelon* fault belts. Any theory that disregards this observational fact should be considered as inadequate. The author does not mention this parallelism of the fault belts with the strike of the regional dip, and the mechanism he suggests would certainly not explain this relation.

ROBERT WESLEY BROWN, Tulsa, Oklahoma: Simple tension under conditions of non-rotational strain should develop fractures at right angles to the direction of tension. Actually this angle may depart somewhat from strict normality, due to irregularities of the material involved, and *en échelon* fractures along a general fracture zone may result as illustrated by Figure 3 of Link's paper on "*En Échelon* Tension Fissures and Faults." However, when such fissures develop, the angle between the trend of the individual fissures and the trend of the fracture zone is ordinarily very small, commonly less than 10°, which might well have been anticipated from the theory of mechanics and the principles of the strain ellipsoid.

In the north Mid-Continent field the angle between the individual fractures and the fault zone is nearly 45°, and this has been explained by Fath, and later by others, as due to rotational stress. The writer considers these differences in the angle between the individual faults and the trend of the fault zone to have an important significance in indicating the origin of the faults,

[1]*Structure of Typical American Oil Fields*, Vol. 1, Amer. Assoc. Petrol. Geol. (1929), pp. 337, 352.

and doubts the possibility of these faults being caused by non-rotational tension.

If the *en échelon* faults of the north Mid-Continent area are due to deformation, either settling or folding over buried ridges as postulated by Link, then one would also expect to find accompanying these zones of *en échelon* faults anticlinal axes coextensive with them, and the absence of such anticlinal axes in this area would require explanation.

W. T. Thom, Jr., Princeton, New Jersey: I desire to express my agreement with the criticisms of Mr. Link's paper registered in the letters which the chairman has read to us. Furthermore, although I believe that the observation of small-scale experiments may give valuable hints as to natural phenomena (as I believe has been demonstrated in Mr. Link's study of epi-anticlinal faulting),[1] I also feel that the method has its pitfalls, and that too great an absorption in laboratory studies may cause one to fail to be aware of the existence of published descriptions of field relations which afford quite conclusive evidence upon the question under investigation.

In the present instance the "Fault Map of California" published by the Seismological Society of America (now seconded by Clark's paper on the Valle Grande)[2] demonstrates that basement fault systems subject to periodic lateral movements do exist on the scale postulated in the Wood-Fath[3]-Chamberlin[4] theory of the origin of *en échelon* fault systems. Ferguson and Willis,[5] Kew,[6] and Eaton[7] have also pointed out the fundamental rôle played by movements on basement faults in the production of the *en échelon* folds of the Los Angles basin; and the most strongly developed of the several *en échelon* fault systems known to the writer—that of southern Montana— is partly covered by publications of the U. S. Geological Survey,[8] and has been the subject of a very able analysis by R. T. Chamberlin.[9] The writer participated in

[1]Theodore A. Link, "The Origin and Significance of Epi-Anticlinal Faults as Revealed by Experiments," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 11 (1927), pp. 853-66.

[2]Bruce L. Clark, "Tectonics of the Valle Grande," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 13 (1929), pp. 199-238.

[3]A. E. Fath, "The Origin of the Faults, Anticlines, and Buried 'Granite Ridge' of the Northern Part of the Mid-Continent Oil and Gas Field," *U. S. Geol. Survey Prof. Paper 128 e* (1920), p. 77.

[4]R. T. Chamberlin, "A Peculiar Belt of Oblique Faulting," *Jour. Geol.*, Vol. 27 (1919), pp. 602-13.

[5]R. N. Ferguson and C. G. Willis, "Dynamics of Oil-Field Structure in Southern California," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 8 (1924), pp. 576-83.

[6]W. S. W. Kew, "A Geologic Summary of California Oil Fields," *Oil Bulletin*, January, 1926.

[7]J. E. Eaton, "A Contribution to the Geology of Los Angeles Basin, California," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 10 (1926), pp. 753-67.

[8]E. T. Hancock, "Geology and Oil and Gas Prospects of the Lake Basin Field, Montana," *U. S. Geol. Survey Bull. 691-D* (1919), pp. 101-47.
"Geology and Oil and Gas Prospects of the Huntley Field, Montana," *U. S. Geol. Survey Bull. 711-G* (1920), pp. 105-48.

[9]R. T. Chamberlin, *ibid.*

the detailed mapping of this zone, and his endorsement[1] of Chamberlin's conclusion that differential lateral movement on a sub-current basement rift was responsible for the production of this fault zone was in part based on items of field evidence which came to his attention during the course of field work. Rubey has also published an analysis[2] of the structural features in surface rocks induced by movements on deep-seated faults—as a sequel to his unpublished studies of the *en échelon* fault belts of the Pawhuska quadrangle, Oklahoma.

It is my belief that if one gives critical study to the evidence afforded by the publicatious cited, he needs must accept the Wood-Fath-Chamberlin theory as to the origin of the Oklahoma and Montana *en échelon* fault systems. Furthermore, when it is recalled that the plaster of a wall is either supported by wooden laths (which undergo lateral swelling and shrinking due to wetting and drying), or by metal netting fastened to studding which shrinks and warps, the diagrams shown by Mr. Link of cracks developing in plaster may, after all, lend support to this theory,—rather than cast doubt upon its validity.

THEODORE A. LINK: Much to my regret it was impossible for me to attend the Fort Worth meeting, at which I had looked forward to an interesting discussion of my paper. In fact, I would much prefer to straighten out the seeming difficulties and misunderstandings by an informal conference with the men who have taken enough interest to submit discussions. As such is, unfortunately, not feasible, I shall attempt to answer the objections by further written discussion.

The first paragraph of Mr. Foley's discussion boils down to the fact that we have different opinions regarding what significance may be attached to structural phenomena produced in the laboratory, as compared with those observed on walls, pavements, *et cetera*, and in the bed rock of the earth's crust. Likewise, Mr. Foley does not believe that the Mexia and Balcones fault systems of Texas exhibit "conditions similar to, but not identical with, the *en échelon* alignment of the Osage faults." Nevertheless, I still do. In Figures 1 and 2 of my article one can observe long and short, forked and continuous *en échelon* tension fissures. Furthermore, the angle relation between the individual fissures and the belts comprising them also varies. In fact, tension fissures observed on plaster walls and concrete-asphalt highways, *et cetera*, may display almost any variety of combinations. The examples illustrated in my paper do not begin to display the variety observable on pavements, walls, highways, *et cetera*. Some resemble the Mexia and Balcones system and others repeat the Oklahoma systems to a marked degree. *En échelon* tension fissures may develop in perfectly straight belts, in arcuate systems, in radial, in concentric, or any other imaginable system. The ultimate system will necessarily pass through the *en échelon* stage if the material is of such nature as described in my paper. As pointed out, if the folding is feeble, the tension fissures may develop only up to the *en échelon* stage; if it is intense, the *en échelon* alignment may be obliterated. If Foley had observed closely the tension fissures which

[1]W. T. Thom, Jr., "The Relation of Deep-Seated Faults to the Surface Structural Features of Central Montana," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 7 (1923), pp. 1-13.

[2]W. W. Rubey and N. W. Bass, "The Geology of Russell County, Kansas," *State Geol. Survey of Kansas Bull. 10*, pp. 75-79.

he produced experimentally he would have noticed them passing through the *en échelon* stage, provided he had performed the experiments slowly enough.

If different areas were subjected to tensile stresses, their individual structural history does not alter the fact that each tension fissure will first pass through the *en échelon* stage. The tensile stresses, operative on a plastered wall, are probably not exactly the same as those operative on a highway, they may not be identical with those operative on the crest of an anticline which is being deformed by tangential compression, or the same as those produced by me experimentally under all sorts of varying circumstances; nevertheless, the *en échelon* alignment is, at a certain stage, observable if the material is of such nature as to cause its development. I do not doubt that the Balcones region is characteristic of regional warping, or, as Lahee suggested, that the Mexia faults "are associated with anticlinal folding in a very significant manner." Tension fissures may be caused by primary tensile stresses or indirectly by a secondary tensional phenomenon accompanying tangential compression as an adjustment feature. This was stated in my paper. Locally, torsion may also be accompanied by simple tension and may give rise to both reverse and normal faulting. However, I concur with Barrell in the opinion that *regional* torsion is a condition difficult to picture. Tension fissures are observable in the most tightly folded strata and also on very feeble structures. I agree with Professor Nevin that there is a distinction between joints and faults. Under some conditions there is a relation, but in others there seems to be none. The relation between the regional dip and the *en échelon* faults is indeed an outstanding characteristic. My explanation is so flexible that it can also be adjusted to that observational fact, as previously mentioned, and for the sake of brevity this was not discussed in detail. The simplicity of my explanation appeals to me as its outstanding feature, rather than an argument against it as concluded by Lahee.

Brown's objection, that the angle-relation between the individual faults and the systems is ordinarily less than 10°, is answered by applying a straight-edge to Figures 1 and 2 and measuring the angles. The angles vary from 0 to 28°. His application of the strain ellipsoid, as well as Foley's, will be answered fully in an article entitled, "The Strain Ellipsoid Is Three-Dimensional," which is now in the hands of the editor of the *Journal of Geology*. In my opinion the strain ellipsoid proves nothing, and has been misapplied too freely as a "smoke-screen."

The last argument by Brown is well taken, but as yet I have not had the opportunity of studying a sufficiently detailed *regional* map showing that there is no general relation between the belts of *en échelon* faults and the anticlinal axes of central Oklahoma. In general, the structures of this area are so feeble that they do not even register in my mind as genuine anticlines. Furthermore, the transmission of stresses through the most competent rock is very limited, as pointed out by McCoy many years ago, and more recently by Lawson.

Professor Thom's discussion is also a fair one, but here again it seems that there is a misunderstanding as to what limitations I am placing on my explanation of *en échelon* tension fissures. If "basement fault systems subject to lateral movements do exist" there seems to be no logical reason why they can not give rise to tensional stresses and if so, the tension fissures developed as a result of these stresses could also pass through the *en échelon* stage.

All of the references cited in Thom's discussion are familiar to me, but I did not refer to them lest my readers might get the impression that I was trying to make a wholesale application of my explanation. I confined my paper to certain Oklahoma and Texas fault systems where, in my opinion, the idea of horizontal basement fault slips had not been demonstrated to the satisfaction of all concerned. Nevin and Sherrill's paper certainly leads one to that conclusion, to say nothing of the informal discussions which I have had with many able geologists actively engaged in field work in these two areas.

Thom's reference to the wooden laths, metal netting, *et cetera*, was seriously considered by me and I was on the point of incorporating a fuller discussion covering that phase in the original paper. However, that would have necessitated a long explanation of the precise reasons why tension fissures develop on an asphalt-concrete highway, on concrete silos or pavements, in linoleum, *et cetera*. Each one of these conditions presents a slightly different *cause* for the tensional phenomenon, but in spite of this fact, each presents the *en échelon* stage sooner or later during the growth of tension fissures. On the same wall from which I took the illustrated examples of *belts* of incipient and arrested *en échelon* tension fissures I also observed and copied other patterns, such as radiating, polygonal, *et cetera*, each of which passes through the *en échelon* stage.

In conclusion, I must admit that if I had enlarged upon some of the statements made in the original article, many of the points brought out in these discussions would have been answered. Finally, I wish to thank those who have taken part in these discussions for displaying an interest, and I hope that my answers will clarify at least some of the points, even though some of us may probably never come to complete agreement.

CAPITAN LIMESTONE AND ASSOCIATED FORMATIONS OF NEW MEXICO AND TEXAS[1]

E. RUSSELL LLOYD[2]
Midland, Texas

ABSTRACT

The Capitan limestone is in part an immense fossil coral reef. The reef itself can be followed from Capitan Point at the south end of the Guadalupe Mountains almost continuously to the vicinity of Carlsbad, New Mexico, where it dips under the plains. The reef formed a barrier separating an open sea with normal marine conditions on the south from a restricted and, in later stages, a super-saline sea on the north. Equivalent formations on opposite sides of the reef are markedly dissimilar. Recognition of buried coral reefs and their relationship is highly important in interpreting the stratigraphy of the Permian basin.

Early in the summer of 1927 W. van Holst Pellekaan pointed out to the writer the reef character of the Capitan limestone, thus directing attention to a study of the characteristics of the Capitan reef and of fossil limestone reefs in general. The proper interpretation of the geology of the Guadalupe Mountains where the Capitan is exposed is believed to be of paramount importance in interpreting the geology of the Permian basin, and the following discussion is offered as a contribution to the major problem. Throughout this discussion the Capitan formation is referred to as a limestone, though it is recognized that much of it is dolomite.

The Capitan limestone and associated formations have been described by Tarr,[3] Richardson,[4] Girty,[5] Darton and Reeside,[6] and others, but these writers evidently overlooked the distinctive reef characteristics.

[1]Read before the Association at the Fort Worth meeting, March 22, 1929. Manuscript received by the editor, February 4, 1929.

[2]Geologist, Fisher and Lowrie.

[3]R. S. Tarr, "Reconnaissance of the Guadalupe Mountains," *Texas Geol. Survey Bull. 3* (1892), pp. 9-39.

[4]G. B. Richardson, "Report of a Reconnaissance in Trans-Pecos Texas, North of the T. & P. R. R.," *Univ. of Texas Bull. 23*, (*Min. Survey Bull. 9*), 1904.

[5]George H. Girty, "The Guadalupian Fauna," *U.S. Geol. Survey Prof. Paper 58* (1908).

[6]N. H. Darton and J. B. Reeside, Jr., "Guadalupe Group," *Bull. Geol. Soc. Amer.*, Vol. 37 (1926), pp. 413-28.

Recent references to the Capitan limestone as in part of reef origin have been made by King and King, quoting Ruedemann,[1] and by Schuchert.[2] The literature on coral reefs is plentiful, especially that dealing with present-day reefs. A very complete summary of both recent and fossil reefs is that by Grabau.[3] The classic descriptions of present-day coral reefs are by Charles Darwin[4] and by J. D. Dana,[5] and this subject has been very fully treated in a recent book by William Morris Davis.[6]

The exposed part of the Capitan limestone extends in a long, narrow zone from Guadalupe Point northeastward to Pecos River just north of Carlsbad, where it dips below the level of the plains. The southeast limits of the limestone are very abrupt and form a scarp which is represented by low hills in the vicinity of Carlsbad, but increases in prominence southwestward to Guadalupe Point, where the top of the cliff is more than 5,000 feet above Salt Flat on the southwest. Almost 2,000 feet of this is a nearly perpendicular cliff of Capitan limestone. The length of the Capitan limestone outcrop is approximately 70 miles, the width is probably not more than 15 miles, and the thickness of the formation is as much as 2,700 feet.

The reef rock proper is well exposed where the road from Carlsbad to Carlsbad Cavern leaves the plains and turns up a canyon cut in the Capitan limestone approximately 23 miles from Carlsbad. It is also exposed in numerous canyons between this place and Guadalupe Point, which itself is predominantly reef rock. It is gray, massive, very porous, and locally highly fossiliferous, and contrasts very sharply with the associated fine-grained, thin-bedded, light buff to cream-colored limestones. The main reef series lies very near the southeast side of the ridge and in many places forms the scarp.

Fossil limestone reefs of Europe and North America have been studied and described in considerable detail and a study of these descriptions and those of present-day reefs leads us to look for certain characteristic features almost invariably associated with reefs. The massive character

[1]Philip B. and Robert E. King, "The Pennsylvanian and Permian Stratigraphy of the Glass Mountains," *Univ. of Texas Bull. 2801* (1928), p. 139.

[2]Charles Schuchert, "Review of the Late Paleozoic Formations and Faunas with Special Reference to the Ice Age of Middle Permian Time," *Bull. Geol. Soc. Amer.*, Vol. 39 (1928), p. 819.

[3]A. W. Grabau, *Principles of Stratigraphy*, pp. 384-447.

[4]*The Structure and Distribution of Coral Reefs*, 3d edition (1889).

[5]*Corals and Coral Islands*, 3d edition (1890).

[6]"The Coral Reef Problem," *Amer. Geog. Soc. Spec. Pub. 9* (1928).

of the reef rocks is one of the most distinctive features. Dolomitization is a characteristic feature of almost all reefs, both recent and fossil. Dolomite is probably not deposited as such, but results from the alteration of calcite or aragonite by reactions within the sediments of the sea bottom.[1] Dolomitization destroys the fossils, as does change from aragonite to calcite. In general, the more complete the dolomitization, the more complete is the destruction of the organic remains until a perfectly homogeneous dolomite may be formed. Many recent coral limestones are quite devoid of organic remains.[2] The Capitan reef rock shows plentiful organic remains, but for the most part so altered that few recognizable forms can be collected. Oölites are a common feature associated with reefs and these are found plentifully northwest of the reef rock proper in the canyon leading to Carlsbad Cavern and in Rattlesnake Canyon a few miles southwest.

We would normally expect to find, on the flanks of an old reef mass, limestone clastics ranging from conglomerates to the finest rock flour. Limestone conglomerate associated with the Capitan reef is not plentiful, but very fine-grained limestones (calcilutites and calcarenites of Grabau) are plentiful. There are also numerous examples of thin-bedded limestone deposited with varying angles of slope on the flanks and over the tops of the reef masses, forming what appear to be pronounced dip slopes. Northwest and west of Carlsbad there are several well developed pseudo-anticlines formed in this manner, on one of which a well was drilled by the Ohio Oil Company a few years ago.

The fauna of the Capitan limestone has been described in detail by Girty,[3] who obtained a large collection of fossils approximately midway up the mountain side near Guadalupe Point. This collection may have been from the reef rock itself or from bedded limestone deposited on the face of the reef. The latter is more probable because fossils are rarely well preserved in reef rock but are ordinarily very plentiful in the inclined beds of the reef flank or fore-reef (Übergussschichtung).[4] In the Capitan fauna as described by Girty corals are very poorly represented, and Ruede-

[1]Edward Steidtman, "Origin of Dolomite as Disclosed by Stains and Other Methods," *Bull. Geol. Soc. Amer.*, Vol. 28 (1917), pp. 431-50.

[2]E. W. Skeats, "On the Chemical and Mineralogical Evidences as to the Origin of the Dolomites of Southern Tyrol," *Quart. Jour. Geol. Soc.*, Vol. 51 (1905), pp. 97-141.

[3]George H. Girty, "The Guadalupian Fauna," *U. S. Geol. Survey Prof. Paper 58* (1908).

[4]Edgar R. Cumings and Robert R. Shrock, "Niagaran Coral Reefs of Indiana and Adjacent States and their Stratigraphic Relations," *Bull. Geol. Soc. Amer.*, Vol. 39 (1928), pp. 579-619.

mann has recently obtained evidence indicating that the Capitan was at least in part of algal reef origin.[1] The scarcity of corals in the fauna as represented in collections, however, does not preclude the idea that corals were important factors in building up the framework of the reef. Locally the reef rock contains numerous fragments of unidentifiable corals.

Three types of coral reefs are recognized in present-day seas—atolls, fringing reefs, and barrier reefs. If any general classification of the Capitan reef can be made it must belong to the barrier-reef type. Present-day barrier reefs, however, are definitely related to land masses near them. Even the Great Barrier reef of Australia is generally parallel with the shore line though it is more than 1,000 miles long and locally more than 70 miles from the coast. The Capitan reef must have been a long distance from any coast line and at present we can not determine the exact location of the coast line. We must remember, however, that the reef developed in a broad, comparatively shallow epeiric sea of which there is no counterpart in recent coral seas.

Barrier reefs are characterized by a steep seaward side exposed to waves and currents and it is under these conditions that the principal reef-building activity takes place. This is also the principal locus of development of steeply inclined beds on the flanks of the reef (fore-reef beds or Übergussschichtung). Shoreward from the reef proper is commonly a lagoonal area, deposits of which are generally characterized by an abundance of marine life and by very fine-grained, bedded limestone deposits interbedded with clastics from the adjacent land.

The seaward side of the Capitan reef was on the southeast. This is shown by the presence of the reef rock on that flank, by the steep scarp, and by much inclined, bedded limestone as well as by the great amount of bedded, fine-grained limestone interbedded with sandstone and shale on the northwest or lagoonal side. Fossil remains, however, are absent or very rare in the bedded lagoonal deposits associated with the Capitan reef and they are probably predominantly chemical precipitates. The principal locus of oölite development was evidently very close to the reef on the lagoonal side, and, according to the writer's interpretation, they are chemical precipitates. Within a comparatively few miles northwest of the reef the upper 800 feet, or more, of the bedded lagoonal limestones grade laterally into gypsum, gypsiferous shales, and sandstones. This feature is well exposed in Rocky Arroyo, approximately 15 miles northwest of Carlsbad, and at many other places from Lake McMillan southwest to a place approximately 6 miles east of Queen Post Office.

[1]Quoted by King and King, *op. cit.*

One of the most striking features of the Permian of southeastern New Mexico is the marked difference in the sedimentary sequence on the north and south sides of the Capitan reef. Correlation of the formations on opposite sides of the reef is very difficult and the data at hand are not conclusive. Table I shows a tentative correlation which is subject to revision as more data are accumulated.

TABLE I

CORRELATION OF PERMIAN OF SOUTHEASTERN NEW MEXICO AND NORTHERN TRANS-PECOS TEXAS

<table>
<tr><th colspan="2">South of Capitan Reef</th><th>In Reef Area</th><th>North of Capitan Reef</th></tr>
<tr><td colspan="2">Upper red beds
Main salt series</td><td>Upper red beds
Main salt series</td><td>Upper red beds
Main salt series</td></tr>
<tr><td colspan="2">Lower salt and anhydrite series</td><td>Anhydrite</td><td>Red shales and anhydrite</td></tr>
<tr><td rowspan="5">Delaware Mountain formation</td><td>Upper dark limestone</td><td rowspan="2">Upper Capitan reef
(Carlsbad limestone)</td><td>Gypsum, red shale, and sandstone
"Red sand" group</td></tr>
<tr><td rowspan="3">Delaware Mountain sandstone</td><td></td></tr>
<tr><td>Lower Capitan reef</td><td>San Andres formation</td></tr>
<tr><td>Sandstone
Gray limestone at Bone Springs</td><td>Glorieta sandstone</td></tr>
<tr><td>Lower black limestone</td><td>Lower black limestone of Delaware Mountain</td><td>Yeso formation</td></tr>
</table>

The Delaware Mountain formation south and southeast of the Capitan reef consists of a lower black limestone of undetermined thickness, a sandstone series more than 2,000 feet thick with interbedded dark shale and limestone, and an upper dark limestone ranging from 30 to 50 feet in thickness. Northward the upper part of the sandstone series grades laterally into the lower part of the Capitan limestone. This lateral gradation is well exposed at the mouth of McKittrick Canyon, where a prominent inclined bed of typical, bedded Capitan limestone is underlain by several hundred feet of Delaware Mountain sandstone which within a few hundred feet interfingers with, and merges into, bedded limestones (fore-reef beds). These in turn merge into the massive non-stratified rock within a very short distance. Similar gradation from sandstone to limestone was seen in the cliffs above Guadalupe Springs and in the cliff near Bone Springs Canyon on the west side of Guadalupe Point. It is estimated that 800-1,000 feet of the upper part

of the Delaware Mountain sandstone is equivalent to, and merges laterally into, the lower part of the Capitan.

The upper dark limestone of the Delaware Mountain formation interfingers with, and grades laterally into, steeply inclined fore-reef beds from the upper part of the Capitan reef. This limestone, not more than 50 feet thick, is believed to be the time equivalent of the upper part of the reef, which is 1,000 feet or more thick.

North of Bone Springs Canyon the lower part of the sandstone series thins markedly in a short distance and a thick gray limestone rests with seeming conformity on the lower black limestone of the Delaware Mountain. The cutting out of several hundred feet of the lower part of the sandstone series and the appearance of several hundred feet of gray limestone within a short distance is interpreted by Darton and Reeside[1] as an overlap, and they mention the deeply eroded edge of the gray limestone member, which they consider the source of the limestone conglomerate between the sandstone and the underlying black limestone member exposed in Bone Springs Canyon. They believe that no great time hiatus is represented by this conglomerate because Guadalupian fossils occur in both the gray and black limestones, and in the overlying sandstone.

The writer's interpretation is that the lower part of the sandstone series merges laterally into the gray limestone just as the upper part merges into the lower part of the Capitan. The gray limestone, like the Capitan, is interpreted as a fossil coral reef, but the evidence is not complete as no actual reef masses were seen in the gray limestone. Some of the cliffs seen at a distance, however, appear massive in character.

South of the Capitan reef the Delaware Mountain formation is overlain by the Castile gypsum. Richardson[2] found some evidence that the Castile is unconformable on the Delaware Mountain formation, and Darton and Reeside[3] state that the Castile gypsum definitely overlies the Capitan limestone.

It has been mentioned that the Permian section north of the Capitan reef is markedly different from that on the south. The section exposed in the Rio Grande Valley and adjacent areas in central New Mexico has been described by Willis T. Lee,[4] whose section is as follows:

[1] *Op. cit.*, p. 421.

[2] *Ibid.*, p. 43.

[3] *Ibid.*, p. 420.

[4] Willis T. Lee and George H. Girty, "The Manzano Group of the Rio Grande Valley, New Mexico," *U. S. Geol. Survey Bull. 389* (1909).

Manzano group	San Andres limestone Yeso formation Abo sandstone
	Unconformity
	Magdalena group

Girty examined the fossils collected by Lee and found no essential differences in the faunas of the three subdivisions of the Manzano group.

Darton[1] later contended that the San Andres and Yeso could be recognized only locally and introduced the term Chupadera formation, which he defined to include the San Andres and Yeso. In his descriptions, however, he included in the Chupadera some beds which are definitely higher than the San Andres. The writer has found that the San Andres and the Yeso are easily recognized throughout extensive areas, both on the surface and from well records, and can see no reason for the inclusive term Chupadera. Between the San Andres and the Yeso is a prominent and widespread sandstone, now commonly known as the Glorieta, which Lee included in the San Andres. The section shown in Table II can be recognized on the outcrop and in the well records of much of east-central New Mexico.

The unconformity between the Abo and the Magdalena is described as very pronounced, and probably represents the time of the main uplift of the ancestral Rocky Mountains, though the presence of arkoses in the Magdalena indicates some earlier uplift in the southern Rocky Mountain area. The Abo is classified as Permian by the U. S. Geological Survey, but C. L. Baker found an ammonoid fauna in the lower part of the formation near Tularosa which Böse determined as Pennsylvanian and correlated with the Cisco.[2]

The Yeso formation is predominantly a red-bed formation, containing much gypsum at the outcrops. Well records, north and northeast of Roswell, show much salt interbedded with gypsum or anhydrite. The basin of Yeso salt-gypsum (anhydrite) deposition was probably limited on the north by the land areas uplifted in the late Pennsylvanian, and on the south by a series of reefs already described as limiting the lower part of the Delaware Mountain sand on the north.

The Glorieta sandstone is very widespread, and is an easily recognized horizon marker in well logs in east-central New Mexico. It is

[1] N. H. Darton, "Geologic Structure of Parts of New Mexico," *U. S. Geol. Survey Bull. 726-E* (1922).

[2] Emil Böse, "On Ammonoids from the Abo Sandstone of New Mexico and the Age of the Beds Which Contain Them," *Amer. Jour. Sci.*, 4th Series, Vol. 49 (1920), pp. 51-60.

TABLE II

TRIASSIC-PERMIAN-PENNSYLVANIAN SECTION, EAST-CENTRAL NEW MEXICO

System	*Formation*	*Character*	*Thickness in Feet*
Triassic	Dockum beds	Santa Rosa sandstone at base	1,700 ±
	Unconformity		
Permian	Upper red beds	Red shale and sandstone	
	Salt anhydrite group	Thick salt beds interbedded with anhydrite and gypsum	1,500 ±
	"Red sand" group	Red and white sandstones interbedded with anhydrite and gypsum	600–800
	San Andres	Limestone, grading northward into salt, anhydrite and gypsum	1,100 ±
	Glorieta sandstone	Medium-grained, buff sandstone, locally interbedded with limestone	10–400
	Yeso	Interbedded gypsum (anhydrite) salt, shale, limestone, and sandstone; predominantly light red colors	1,000 ±
	Abo	Brick red sandstone, arkose, red sandy shale and beds of limestone	800 ±
	Unconformity		
Pennsylvanian	Magdalena	Predominantly limestone with inter-interbedded shale and sandstone	1,500-2,000

probably the same as the Coconico sandstone of Arizona and Utah, which locally has a thickness of as much as 1,000 feet. Near Vaughn, New Mexico, the Glorieta is more than 400 feet thick, but there is a marked decrease in thickness toward the east and south. The origin of the Glorieta sand was probably on the northwest, possibly in mountainous areas in Nevada.

The San Andres is described by Lee and others as a limestone, but throughout extensive areas it is represented in part by salt and anhydrite. Well records east of Roswell show a thickness of approximately 1,100 feet and in this region it is almost all limestone with only a few thin beds of anhydrite and sandstone near the top. Farther south, near Artesia, it seems to be all limestone (or dolomite) and sandy limestone. The productive oil horizons in the Artesian field are in the upper part of the San Andres, aud the artesian water in the Roswell-Artesia basin comes from porous zones in the upper part.

West and northwest of Roswell, beds of gypsum interbedded with limestone were found in the upper part of the San Andres, but southeast of Fort Sumner, 80 miles north of Roswell, well records show that only the lower 275 feet of the San Andres is limestone, the remainder being an alternating series of salt and anhydrite.

The correlation on the south is still somewhat uncertain, but the San Andres is very probably the equivalent of the lower part of the Capitan, which in turn is equivalent to the upper part of the Delaware Mountain sandstone. The San Andres is tentatively correlated with the Kaibab limestone of Utah and Arizona.

Outcropping in the valley of Pecos River, east and northeast of Roswell, is a group of sandstone beds interbedded with gypsum. The sandstone is very fine-grained and friable, occurs in beds as thick as 60 feet, and is the predominant feature within an interval of 800 feet. The base of the predominantly sandy phase is considered the top of the San Andres. This sandstone group is equivalent to a part of the "Seven Rivers gypsum member of the Chupadera"[1] and is probably the same as a series of fine-grained white and buff sandstones interbedded with limestones exposed in the vicinity of Queen Post Office in the Guadalupe Mountains, west of Carlsbad.

The individual beds of the "Red sand" group thin out south from Roswell, and in the Artesia and the Maljamar oil fields the most of the interval is represented by anhydrite and gypsum with a few comparatively thin beds of sandstone. One of these beds is the "Red sand" commonly used as a datum horizon in contouring in these fields.

Northward from Roswell the "Red sand" group becomes more predominantly sandstone. Well-log correlations across the "South Plains" district of Texas indicate that it is the same as the Whitehorse sandstone of Oklahoma, a correlation suggested by Beede several years ago on faunal evidence.

In central New Mexico, Arizona, and Utah no Permian deposits younger than San Andres and Kaibab are known, and it is probable, though not certain, that no higher Permian beds were deposited west of the present eastern mountain ranges of New Mexico.

The salt-anhydrite group is known principally from well records inasmuch as much of its outcrop is concealed by overlap of Triassic red beds, and by wind-blown "Mescalero" sands.

We have already seen that the Capitan is a huge reef or series of reefs extending northeastward 70 miles or more from Guadalupe Point, and well records enable us to project it far out under the plains region. It will be noticed that in the basin north of the Capitan Ridge gypsum (or anhydrite) and salt are present in all formations above the Abo.

[1]Oscar Meinzer, B. Coleman Renick, and Kirk Bryan, "Geology of No. 3 Reservoir Site of the Carlsbad Irrigation Project, New Mexico, with Respect to Water Tightness." *U. S. Geol. Survey Water Supply Paper 580-A* (1926).

South of the ridge we have no record of gypsum or anhydrite until after the close of Delaware Mountain.

All authorities agree that Paleozoic reefs were built up under conditions similar to those under which recent coral reefs are formed. We can assume a maximum depth of reef-building activity of approximately 25 fathoms, an annual minimum temperature of 68° F., and an average temperature of 70° or higher. Present-day reef-building organisms flourish only on firm or rocky bottoms without silty deposits and in agitated and circulating waters and we can safely assume similar conditions for the Permian reefs.

In one respect, at least, the Capitan reef has no counterpart in recent seas: the Capitan reef was built in close association with seas that were depositing anhydrite and salt. We have seen that the lagoonal limestones associated with the Capitan reef intergrade laterally on the north with a gypsum red-bed series at a point not far distant from the reef itself. The fauna of the Capitan has been characterized as a cosmopolitan, open-sea, coastal-shelf fauna,[1] and we must postulate for its environment conditions not markedly different from those of present-day open seas. The oceans at present contain approximately 35 grams per litre of salts in solution and a concentration of more than 200 grams per litre is necessary before gypsum will be precipitated.[2] Although we might assume that reefs could grow under conditions of salinity considerably in excess of those of the present oceans, we can scarcely assume that reef-forming conditions were possible with a salinity anything like that necessary for the precipitation of calcium sulphate. We must therefore assume some kind of a barrier separating the nearly normal sea water of the reef tract from the super-saline waters on the northwest. The reef itself seems to have formed that barrier.

Should we accept the view held by many geologists that the Castile is equivalent to, and grades into, the Capitan, we would have to account for reef-building conditions extending through a considerable period of time in a long narrow zone in the midst of a highly super-saline sea.

The writer holds to the theory that the Capitan Reef formed a barrier between open-sea conditions on the southeast and super-saline conditions on the north. Deposition in the super-saline basin on the north, consisting in part of clastic sandstone and shale from some land

[1] J. W. Beede, Review of "The Guadalupian Fauna" by George H. Girty, *Jour. Geol.*, Vol. 17 (1909), pp. 672-79.

[2] From results of Usiglio's experiments quoted by A. W. Grabau, *Principles of Salt Deposition* (1920), p. 51 *et seq.*

area, in part of anhydrite or gypsum chemically precipitated, and in part of chemically precipitated limestone, kept pace with the growth of the reef. This holds true particularly for the later stages of the growth of the Capitan reef. During the earlier stages the waters were more nearly normal sea water on the north as well as on the south.

The San Andres, which is correlated with the lower part of the Capitan, is a normal marine bedded limestone as far north as Roswell and contains a marine fauna which is, however, quite different from the Guadalupian fauna of the Capitan. The difference in the fauna may be explained by differences in environment. The Capitan (Guadalupian) fauna is a clear-water, open-sea, shallow-water fauna, but the San Andres (Manzano) fauna was developed in a more or less restricted sea as suggested by Darton and Reeside.[1]

According to this interpretation the lower part of the Capitan reef formed a barrier between the open sea on the south in which the upper part of the Delaware Mountain sandstone was deposited and the partly restricted sea on the north in which the San Andres limestone was deposited and in the same way the upper part of the Capitan reef formed a barrier between an open sea on the south in which very slow deposition was taking place (represented by the upper dark limestone of the Delaware Mountain formation) and a super-saline sea on the north in which gypsum (or anhydrite), red shale, and sandstone were deposited.

The Yeso formation, underlying the San Andres, was deposited in a super-saline sea. As it is evidently equivalent in time to the lower part of the Delaware Mountain formation, it is almost necessary to assume some kind of barrier between the two areas. The reef (as the writer interprets it) of gray limestone north of Bone Springs Canyon probably formed this barrier.

Cumings and Schrock have described the Niagaran coral reefs of Indiana and adjacent states[2] as "the grandest system of fossil reefs on the American Continent." The Capitan reef is one of a group of reefs on the southwest side of the Permian basin beside which the Niagaran reefs pale into insignificance. The largest reefs in the Niagaran are approximately a mile in diameter and 100 feet high, but the Capitan reef in its exposed part alone is approximately 70 miles long and more than 2,000 feet high. The massive reefs of the Apache Mountains and the Vidrio limestone of the Glass Mountains are comparable in size and the whole group is comparable with the dolomite reefs of southern Tyrol.

[1]*Op. cit.*, p. 427.

[2]*Ibid.*, p. 599.

It is not the purpose of the writer to enter into a discussion of the many problems of the stratigraphy of the Permian basin, but it should be pointed out that the recognition of buried coral reefs in the basin and a study of their relation to other rocks have been found to be of paramount importance, because of the intimate relation between the reefs and the origin and accumulation of oil.

DISCUSSION

F. S. PROUT, Roswell, New Mexico: Is the upper black lime of the Delaware equivalent approximately to Mr. Lloyd's terminology of Capitan?

The Queen sand zone is within that distance (approximately 100 feet) from the top of El Capitan; thus, if the top of the Delaware (corrected by Mr. Lloyd to Delaware sand series) is near the top of the cliff, it is approximately equivalent to the Queen sand zone, which therefore leaves the overlying thinner-bedded limes above the Delaware sand. This series of limestone thickens northward toward Carlsbad with the Queen sand zone below the Seven Rivers gypsum and in the top of the San Andres. Therefore I believe, as does Mr. Crandall, that the term Carlsbad should be retained for the upper beds.

The structural and topographic feature termed the Bone Springs arch and including the Bone Springs and Tank Canyon arches, had a profound influence on deposition in overlying beds.

The gray upper member of the Bone Springs series is not a reef. It shows profound channeling, with Delaware sand deposited in the channels with limestone on either side of the sand and with no gradation.

A conglomerate is also present at the base of the Delaware sand northward of the Bone Springs Canyon near the New Mexico state line.

E. RUSSELL LLOYD: The name Capitan limestone was first used by Richardson[1] for the massive white limestone exposed at Guadalupe Point and El Capitan Peak. Most of the limestone exposed in this cliff is reef rock, but there are some underlying bedded limestones separating the massive limestone from the underlying sandstone of the Delaware Mountain formation. I have included in the term "Capitan limestone" all of the reef rock exposed between Guadalupe Point and the vicinity of Carlsbad, and also bedded fore-reef and lagoonal limestones contemporaneous in age with the reef. I have also included bedded limestones of undetermined thickness overlying the reef rock. In this I have undoubtedly included in the term beds stratigraphically higher than those exposed at El Capitan Peak. The "upper dark limestone" of the Delaware Mountain formation is believed to be the time equivalent of approximately the upper half of the Capitan limestone, though it is possible that the bedded limestone overlying the reef rock is later than the upper dark limestone.

I have made no detailed studies of the sandstone series exposed in the vicinity of old Queen Post Office. This series will, I believe, be named and

[1] G. B. Richardson, "Report of a Reconnaissance in Trans-Pecos Texas north of the Texas and Pacific Railway," *Univ. Texas Bull. 23* (*Min. Survey Bull. 9*) (1904), *p. 40*.

described in a forthcoming paper by Blanchard and Davis. I have tentatively correlated it with an unnamed "red sand" group exposed east of Roswell, New Mexico, which I have considered as overlying the San Andres formation. The "Carlsbad limestone member of the Chupadera formation" as defined by Meinzer, Renick and Bryan[1] is a part of the lagoonal limestone series associated with the Capitan reef and is for the most part, at least, equivalent in age with the upper part of the reef rock.

Mr. Prout has voiced a disagreement held by several others with my statement that north of Bone Springs Canyon the lower part of the Delaware Mountain sandstone merges laterally into gray limestone and that his gray limestone is of organic reef origin. Recently I revisited the locality in company with P. F. Brown. We went up Bone Springs Canyon to the base of the Delaware Mountain sandstone, where we found the conglomerate as described by Darton and Reeside, overlain by sandstone, this sandstone horizon in turn overlain by gray limestone in a fairly thin series of beds, and this overlain by the main sand series. On following the base of the sand series toward the north, we found the gray limestone increasing in thickness. The lowest sandstone zone persists to the cliff south of the first small canyon north of Williams Ranch, where it disappears and the interval is represented by limestone. Directly north of this small canyon we saw the "eroded edges of the gray limestone" as described by Darton and Reeside, but these "eroded edges" are overlain not by a conglomerate or by sand, but by a thin-bedded limestone or limy shale, and this in turn by sandstone. At the same time we saw in the cliffs, both in the gray and the black limestones, several examples of "local unconformities" such as that in Bone Springs Canyon pictured by Darton and Reeside. These I prefer to consider as cross-bedding on a large scale. The "eroded edges of the gray limestone" may be further examples of such cross-bedding.

The lowest sandstone zone, at least, merges laterally into limestone, but we saw no other interfingering of the sandstone with the gray limestone, though the lower part of the sandstone near Goat Seep Canyon is very calcareous. The relation of the sandstone to the gray limestone may be interpreted as in part one of interfingering and in part of overlap. Either interpretation is consistent with the theory that the gray limestone is of reef origin. Our present conception of the gray limestone is not that of a single massive reef like the Capitan, but of a series of small reefs interbedded with fore-reef and lagoonal limestones. Some of the massive limestone beds exposed in Goat Seep and other canyons may be reef rock, and the large-scale cross-bedding in both the gray and the black limestones may be due to inclined deposition on the flanks of the reefs and in inter-reef areas.

R. J. METCALF, Fort Worth, Texas: I believe that Mr. Lloyd has failed to recognize the importance of structure in the formation of the barrier. The structural arch produced conditions, I believe, which started the formation of the coral reef. His discussion of associated formations is very good.

[1]Oscar E. Meinzer, B. Coleman Renick, and Kirk Bryan, "Geology of No. 3 Reservoir Site of the Carlsbad Irrigation Project, New Mexico, with Respect to Water Tightness."

E. Russell Lloyd: That structural conditions in some places may have been very influential in producing conditions favorable for the beginning of reef growth can not be denied. The location of a reef is determined in large part by the topography of the sea floor at the time reef growth begins. Any folding which took place in pre-Permian or early Permian time undoubtedly influenced the topography of the sea floor at later stages. Reefs developed at one stage were also important in determining the position of later reefs, some of which are, and others are not, directly superimposed on the older reefs. Just what bearing the prominent feature commonly known as the "Bone Springs arch" had in determining the position of the later Capitan reef is not evident. Whether interpreted as of reef or structural origin, it undoubtedly formed a prominent topographic "high" in the Permian sea floor, but in the vicinity of Bone Springs Canyon this topographic "high" was to a large extent obliterated by the deposition of Delaware Mountain sandstone prior to the beginning of the Capitan reef.

Ronald K. DeFord, Roswell, New Mexico: Lloyd mentioned (page 650) the contact of the Delaware Mountain sandstone with a gray limestone, the so-called Bone Springs limestone. The place described is along the western face of the Guadalupe Mountains a mile or two north of Guadalupe Point, in the vicinity of Bone Springs Canyon on Williams Ranch, northern Culberson County, Texas (Secs. 39, 46, and 47, Bl. 66, T. 1). George D. Riggs, of The Midwest Exploration Company, Amarillo, has sent me a brief and characteristic discussion, here quoted in full.

Fig. 1.—Bedded Delaware Mountain sandstone, upper right; massive gray hackly dolomite (Bone Springs limestone), lower left.

"About this contact E. Russell Lloyd says:

"'*The writer's interpretation is that the lower part of the sandstone series merges laterally into gray limestone just as the upper part merges into the lower part of the Capitan.*'"

"I took this picture on our last trip. It was taken near the head of Goat Canyon."

HOTCHKISS SUPERDIP: A NEW MAGNETOMETER[1]

NOEL H. STEARN[2]
St. Louis, Missouri

ABSTRACT

The purpose of this new instrument is to aid in the search for valuable mineral deposits.

The history of the instrument culminates in an intensive testing period of 2½ years, during which time it has been tested in the field in Arizona, Mexico, New Mexico, Texas, Oklahoma, Arkansas, Kansas, Missouri, Illinois, and Wisconsin.

In principle the instrument is designed to measure slight variations in the earth's magnetic field.

The construction of the Superdip is designed to withstand rough field use.

Its manipulation has been simplified to the utmost extent commensurate with reliable results.

The corrections for very precise work are made by eliminating the effects of temperature, diurnal variation, latitude, and longitude.

The sources of error, including manipulative, mechanical, and magnetic sources, have been evaluated as closely as possible to date.

The field procedure routine has been evolved to eliminate lost motion.

The application of the instrument to the oil business is exemplified by a picture of the results of a survey made in the Panhandle of Texas, drawn in isometric form.

PURPOSE OF INSTRUMENT

The immediate function of the Hotchkiss Superdip magnetometer is to detect and measure the comparative magnitude of variations in the earth's magnetic field. The ultimate object is to assist in locating deposits of valuable natural resources such as oil, coal, metalliferous ores, and non-metallic mineral deposits. The relation between valuable natural resources and variations in the earth's magnetic field is not necessarily direct,[3] although certain ore deposits directly cause certain magnetic anomalies. Generally, however, the natural resources have some genetic or structural relation to certain rock formations which, by virtue of their differential magnetic permeabilities, cause variations in the earth's magnetic field. Thus, in so far as the measurement of mag-

[1]Presented before the Association at the Fort Worth meeting, March 22, 1929. Manuscript received by the editor, February 18, 1929.

[2]704 Shell Building.

[3]Noel H. Stearn, "A Background for the Application of Geomagnetics to Exploration," *Amer. Inst. Min. Met. Eng. Tech. Pub. 150* (1928).

netic anomalies is an aid to deciphering the geology of an area, it is indirectly an aid to prospecting the area for natural resources.

HISTORY OF DEVELOPMENT

When W. O. Hotchkiss, now president of the Michigan College of Mines and Technology, was doing geological work on the iron ranges of the Lake Superior region, he made extensive use of the ordinary dip needle as an aid to tracing rock formations in regions covered by glacial drift. Although this instrument proved very satisfactory for the work involved, Hotchkiss conceived the idea of making an instrument much more sensitive to slight variations in the earth's magnetic field, so that the use of magnetics in the solution of geological field problems would have a wider range of applicability. He therefore hit upon the principle by which an instrument of the general type of the dip needle can be made to attain theoretically infinite sensitivity, that is, can be made to register infinitely small changes in the earth's magnetic field except in so far as limited by mechanical friction.

After the mathematical basis of this principle had been confirmed by Gordon Scott Fulcher, Hotchkiss took it to John P. Foerst, technician for the department of physics at the University of Wisconsin, whose mechanical ingenuity succeeded in embodying the idea in a model.

The first model proved the prospective workability of the principle. But Hotchkiss' duties as state geologist of Wisconsin at that time prevented his developing the idea. He was associated on the Wisconsin Geological Survey with H. R. Aldrich, now assistant state geologist of Wisconsin, who was engaged on an extensive project of magnetic mapping in northern Wisconsin with the ordinary dip needle. With his background of experience Aldrich proceeded to carry on the development of the Hotchkiss instrument.

Its first introduction into the oil business was through Aldrich's experimental work for the Gulf Company in Texas, when the instrument was in its original undeveloped stage. At that time many mechanical features were found to be unfieldworthy, and the application of the principle was only partly understood. The Gulf Company abandoned the experiment, and the difficulties were attacked by the writer, a former assistant of Hotchkiss and Aldrich on the Wisconsin Geological Survey.

Through the writer the instrument was introduced to W. C. McBride, Inc., of St. Louis, Missouri. Recognizing at once the potentialities of the instrument as well as its need for further development, that company proceeded to organize the four men responsible for the instru-

ment, Hotchkiss, Foerst, Aldrich, and Stearn, into a serious attempt to solve the problem of creating a highly sensitive instrument with a maximum of simplicity and fieldworthiness. The mechanical work was done by Foerst, the laboratory work by Aldrich, and the field work and general supervision by the writer.

This organization has effected nearly 40 changes in the original model, ranging from the mechanics of the mounting to the metallurgy of the magnet steel, and has succeeded in producing a simple, sensitive, and fieldworthy instrument which has been patented by W. C. McBride, Inc. The developmental period has so far required approximately 2½ years, and the instrument has been tested throughout large parts of Texas, Oklahoma, Arkansas, and Kansas, and in certain localities in Mexico, New Mexico, Arizona, Missouri, Tennessee, Illinois, and Wisconsin.

PRINCIPLES

The principle involved in the design of the instrument takes account of the fact that the core of the earth acts as a magnet and the outer shell of the earth is within the magnetic field of that magnet. A magnetic field is defined by "lines of force" which normally undergo a symmetrical variation in direction and intensity according to their distance and direction from the poles of the magnet. At the magnetic poles of the earth the lines of force are vertical in direction and the field has a maximum intensity. At the magnetic equator the lines of force are horizontal and point toward the poles, and the field has a minimum intensity. The symmetry of the variation between these two extremes is locally interrupted by anomalous bunchings and thinnings of the lines of force. These are due to the fact that the earth's magnet is deep-seated, and the lines of force which define its field must pass through the outer crust of the earth. Because the rocks which make up this crust have different magnetic permeabilities, the lines of force seek to crowd through certain rocks and to avoid other rocks. It is safe to say that, in the broadest sense, every natural magnetic anomaly has a definite geological meaning. To locate these anomalies is the function of this instrument. To discipher their meaning is the function of a geologist.

A small bar magnet free to move, invariably aligns itself with the earth's magnetic field. It can, therefore, show changes in direction in that field, but it can not show changes in intensity. If, however, the small magnet is forced into a position out of alignment with the earth's field, a certain magnetic force will immediately be exerted upon it to bring it back into alignment. If just enough artificial force is applied

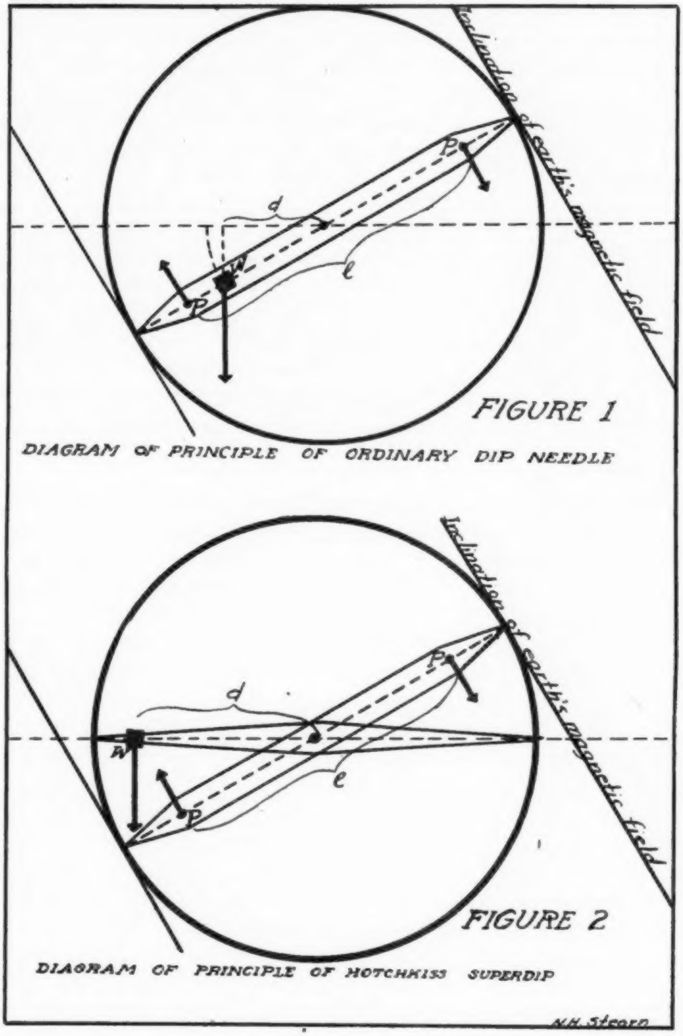
to the magnet to hold it in a certain position relative to the earth's field at a certain place, and the magnet is then moved to another place where the force of the earth's field is different, then the artificial force is no longer exactly compensated and the magnet must change its position. Such a change in position, therefore, indicates a change in the magnetic force, and the magnitude of the change in position is an index of the magnitude of the change in intensity of the earth's field.

All instruments designed to utilize these principles balance the force of gravity against the magnetic force in some controlled relation to the plane of the magnetic meridian. For example, the ordinary dip needle[1] consists of a bar magnet suspended with fixed bearings in such a way that it can move in a single plane, and supplied with an adjustable counterweight on the magnet, which serves to balance it at an angle to the inclination of the earth's field when the instrument is oriented in the plane of the magnetic meridian, thereby introducing the action of two forces, the resultant of which determines the position of rest of the magnet. The force of gravity is assumed to be relatively constant in direction and intensity from place to place, but its effect on the balanced magnet varies because it is applied as a turning moment opposed to that of the magnetic force (Fig. 1).

The magnetic moment M is the product of the strength of the earth's field I and the magnetic moment of the magnet, which is the product of the pole strength P of the magnet and the effective length of its axis l. Thus $M = IPl$; and is clearly at its maximum when the axis of the magnet is at right angles to the inclination of the earth's field as shown in Figure 1. But the turning moment of gravity which holds the magnet in that position is the product of the weight of the counterweight W and its effective distance from the fulcrum d (Fig. 1). Thus $G = Wd$; and this value is not at its maximum unless the magnet is horizontal. However, in any position of rest $IPl = Wd$. But if by reason of a change in the intensity of the earth's field the magnet is caused to move toward the horizontal position, two changes take place. The factor l is decreased, thus decreasing the proportion of M acting on the magnet, and the factor d is increased, thus increasing the proportion of G acting against M. Thus the sensitivity of the instrument is impaired.

If, however, in the same balanced system the counterweight is so arranged that G and M are simultaneously at their maximum, then their effective lever arms will change in the same proportion, with any change

[1]Noel H. Stearn, "The Dip Needle as a Geological Instrument," *Amer. Inst. Min. Met. Eng. Tech. Pub. 151* (1928).


Inclination of earth's magnetic field
P
d
W
ℓ
P
FIGURE 1
DIAGRAM OF PRINCIPLE OF ORDINARY DIP NEEDLE
Inclination of earth's magnetic field
P
d
W
ℓ
P
FIGURE 2
DIAGRAM OF PRINCIPLE OF HOTCHKISS SUPERDIP
N.H. Stearn

FIGS. 1 and 2

in the position of the magnet. This can be accomplished by making d horizontal when l is at right angles to the direction of the earth's field (Fig. 2). Thus $IPl = Wd$ as before. But suppose the magnet were forced to turn through any angle a. The effective arms are now reduced to $d \cos a$ and $l \cos a$, the turning moments are $Wd \cos a$ and $IPl \cos a$, and both sides of the equation are diminished by the value of a common factor, $\cos a$.

This means that the needle (magnet) is in unstable equilibrium and the slightest change in the magnetic force M, either increase or decrease, results in turning the needle (magnet) 90° from the position shown in the figure. It is obvious that the only bar to infinite sensitiveness in this instrument is the lack of mechanical perfection in its making.[1]

It is also obvious that any degree of practical sensitivity, from that of the ordinary dip needle to that of theoretical infinite sensitivity limited only by friction, can be obtained by varying the angle between d and l. This is the basic principle of the Hotchkiss Superdip.

CONSTRUCTION

In designing the mechanical embodiment of this principle, every effort has been focused on securing the utmost simplicity commensurate with the accuracy necessary to its proper functioning as a geological instrument. Complete visibility and ready accessibility of all essential parts is accomplished in the construction as shown in Figure 3.

The most important mechanical feature is the magnet system or swinging assembly (*B*, Fig. 3), the major element of which is a bar magnet (*26*) made of a special tungsten-cobalt steel and so mounted that it is free to move in a vertical plane. To this are attached counterarms (*32*, *33*) which can be adjusted to some known angular relationship to the axis of the magnet. The angle between the counterarm and the magnet is measured by the arcuate scales (*35*) or by an especially designed protractor. The whole assembly is affixed to a pivot (*18*) at its center of gravity, so that without the counterweight the assembly is perfectly balanced. Then to one counterarm is added the counterweight (*34*) which can be adjusted by varying its effective lever arm.

This swinging assembly is mounted in the instrument by resting the ends of the pivot (*18*) on two parallel and horizontal agate edges (*16*). For insurance against damage during transportation, the swinging assembly is lifted from the agate edges by a release device (*36*) and clamped against the pivot guides (*17b*) which automatically center the whole assembly.

[1] W. O. Hotchkiss, "Magnetic Methods for Exploration and Geologic Work," *Amer. Inst. Min. Met. Eng. Pub. 1232-M* (1923).

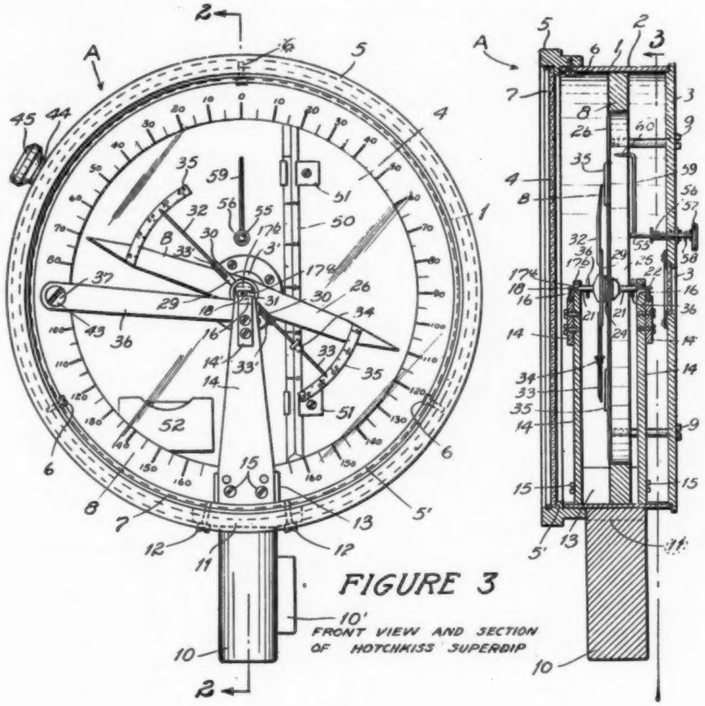


FIG. 3

For determining variations in the position of the swinging assembly, a circular scale (*8*) graduated into degrees of arc is so placed that the magnet swings in its plane.

Since temperature changes cause appreciable variations for sensitive settings of the instrument, these must be corrected out. To this end a thermometer (*50*) is installed in the instrument.

For greater speed and accuracy the instrument is read on the swing from the zero position. To return the swinging assembly to the zero position a mechanical finger (*59*) is fitted into the back of the instrument.

The swinging assembly, release device, scale circle, thermometer, and mechanical finger are all enclosed in a cylindrical brass case with a glass face (*4*) which is easily removable by a single wrist movement, so that the interior of the instrument is always visible and quickly acces-

sible. The weight of the instrument is approximately 2 pounds and its size is 5¼ by 1½ inches so that it can easily be worn on the belt.

This instrument is mounted on a tripod with a four-screw leveling head (Fig. 4) on which adjustable level bubbles have been so oriented as to give the instrument the correct position when they are levelled.

A compass fitted to the same tripod is necessary to determine the plane of the magnetic meridian in which the magnet assembly must swing.

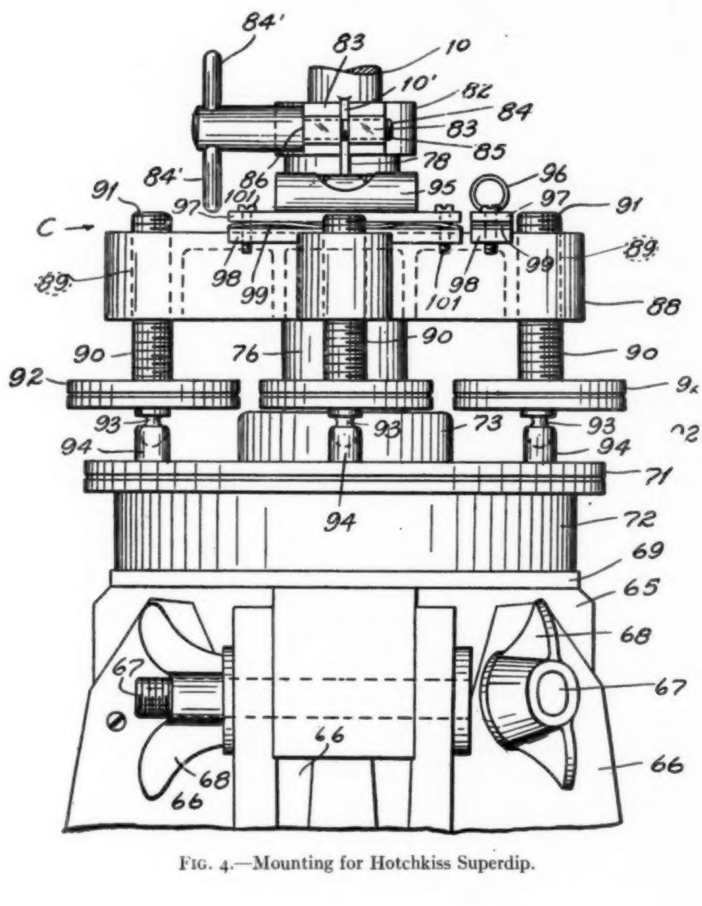


FIG. 4.—Mounting for Hotchkiss Superdip.

MANIPULATION

Suppose the instrument be taken into a new and unknown area. The following procedure serves to make the proper setting.

SETTING

1. Locate a point near the center of the area to be surveyed, or where the earth's magnetic field is thought to be normal for the area.

2. Determine the direction of the earth's magnetic meridian with the compass.

3. Determine the inclination of the lines of force of the earth's field. This is done by mounting the instrument on the tripod, removing the counterweight from the swinging assembly, and setting the counterarms parallel with the axis of the magnet. As the swinging assembly is pivoted at its center of gravity, it will align itself with the direction of the lines of force. The angle of inclination can then be gotten from the scale circle.

4. Set the sensitivity of the instrument. As the angle between the counterarms and the axis of the magnet determines the relative sensitivity of the instrument, the counterarm is adjusted to any desired angle. The limiting angle is determined by the angle of inclination of the earth's field. Suppose that angle to be 60° (Fig. 5). Then the angle between the counterarm and the magnet (angle A) should be 30° in order to attain theoretically infinite sensitivity, for in this position when the magnet is at right angles to the earth's field the counterarm is horizontal. But infinite sensitivity is not desirable for field work. Consequently the angle actually set off (T) is less than the angle of infinite sensitivity. The difference is the angle S. For general reconnaissance work in the latitudes of the United States the angle S is set from 1° to 2°.

5. Adjust the position of rest of the magnet. With the angle T measured off, the counterweight is applied to the counterarm and adjusted until the position of rest of the magnet is approximately at right angles to the inclination of the earth's field.

Under normal conditions, the time required for the whole process of setting the instrument ranges from 10 to 20 minutes.

READING

The actual reading involves the following procedure.

1. Set up the tripod and adjust the leveling head.

2. Mount the compass and determine the magnetic meridian, that is, magnetic north.

3. Remove the compass and mount the instrument.
4. Move the swinging assembly to the zero position.
5. Release it and record the end of its swing, the temperature, and the time.
6. Check the reading.

This process can be accomplished in less than 1 minute by an expert manipulator.

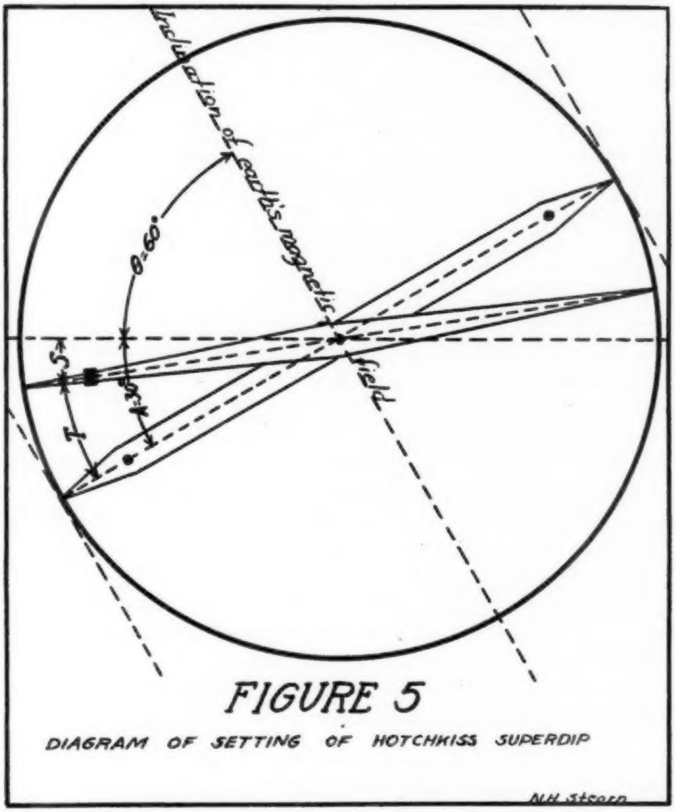


FIGURE 5

DIAGRAM OF SETTING OF HOTCHKISS SUPERDIP

FIG. 5

CORRECTIONS

To secure extremely precise results, five different corrections may be applied to the readings. These corrections have differing degrees of importance, and in some surveys are totally unnecessary. It should be borne constantly in mind that a magnetic survey is not an end in itself, but merely a means to aid geological interpretation, and the importance of corrections should be evaluated in relation to that function.

1. *Temperature.*—The temperature coefficients of the instrument for various values of the angle S are determined in the laboratory in terms of instrument scale divisions and of gamma. However, it is a simple matter to check these in the field. In fact, the laboratory constants are unnecessary. If the instrument is warmed or cooled artificially and the change in readings recorded while it is acclimating itself, the temperature coefficient can easily be determined. This is really a daily procedure, for the instrument must be allowed to acclimate itself in the morning before taking the first reading.

2. *Diurnal variation.*—A magnetic variation of differing intensity occurs daily. This has nothing to do with anomalies caused by rock formations, and hence should be eliminated from the readings if its order of magnitude approaches that of the anomalies. It has been found practicable to do this by revisiting a hub station at intervals during the day. The frequency of the intervals depends upon the precision considered necessary.

3. *Day-to-day variation* may introduce discrepancy into surveys covering an extended period of time. It is due to cyclic magnetic variations of longer periodicity than the diurnal variation. It can be eliminated by checking daily on a hub station.

4. *Latitude.*—This correction is necessary only to reduce results to a horizontal plane. If it were easy to visualize anomalies referred to an inclined plane or a curved surface the correction would be entirely unnecessary. For this instrument the latitude correction is a curve, because of the fact that the angle of inclination of the earth's field varies with the latitude, and the angle S of the setting varies with the angle of inclination.

5. *Longitude.*—This is just a phase of the latitude correction which is introduced by the fact that magnetic north and geographic north are not coincident. It is taken care of in the latitude correction.

Figure 6 shows a profile from Pampa, Texas, to the south line of Gray County. It is plotted to show the influence of the various corrections on the original profile. It can be seen that here the temper-

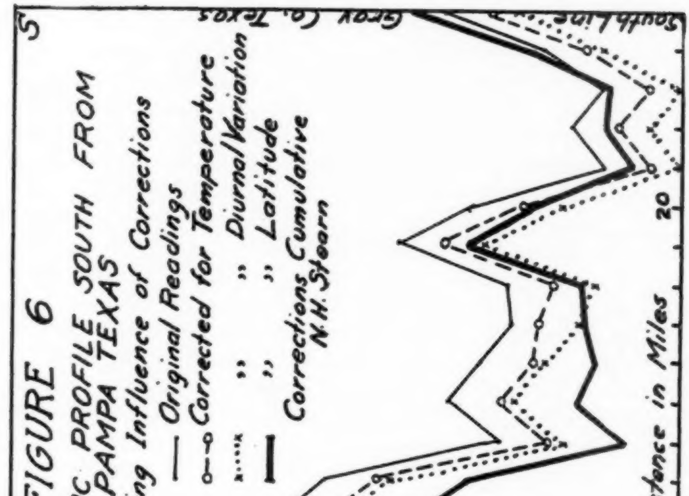


FIGURE 6
MAGNETIC PROFILE SOUTH FROM PAMPA TEXAS
Showing Influence of Corrections
Original Readings
Corrected for Temperature
" " Diurnal Variation
" " Latitude
Corrections Cumulative
N.H. Stearn
N
S
PAMPA Magnetic Relief in Scale Divisions
80
70
60
50
40
30
20
10
North Ridge
Bowers Pool
South Ridge
Gray Co. Texas
South Line
Distance in Miles
5
10
20

FIG. 6

ature and diurnal variation corrections have little influence in changing the shape of the profile. Obviously the general geological factors stand out in the first profile as clearly as in the last. However, in areas where the magnetic relief is less pronounced these corrections become essential.

SOURCES OF ERROR

In any field instrument there must necessarily be a compromise between absolute precision on the one hand and flexibility, speed, and simplicity on the other. But this compromise should be thoroughly evaluated. The possible influences which might introduce error are mechanical, manipulative, and magnetic.

MECHANICAL SOURCES OF ERROR

1. *Setting.*—In setting the instrument the significant thing is the angle S (Fig. 5). Because of parallax and of possible error in the balance of the swinging assembly, this angle can be depended upon only to within approximately ⅛ degree. However, since the whole principle of the instrument involves relative values, this fact introduces no possibility of error except in connection with applying the latitude correction. And even in that connection the error is negligible relative to the geological significance of the results.

2. *Swinging.*—The rolling bearing of the pivot introduces an error of approximately ½ scale division in 360, or a ratio of 1 to 720.

Through a range of approximately 80 scale divisions the response of the instrument is directly proportional to the change in the earth's field. Beyond this range there is a gradual increase in the amount of change in the earth's field necessary to produce a given change in the instrument reading. This means merely that extreme anomalies are automatically dampened and brought within instrument range without losing their geological significance, or necessitating a change in instrument setting.

MANIPULATIVE SOURCES OF ERROR

1. *Instrument.*—Variations in the orientation of the instrument relative to the magnetic meridian, in the leveling, in the position of the swinging assembly relative to the zero position, and in the releasing of the swinging assembly, introduce variations in the instrument readings which seldom exceed one scale division in amount, even for very sensitive settings of the instrument under average rapid manipulation.

2. *Corrections.*—By virtue of their nature, the corrections are always close approximations. The difference between these approxima-

tions and the actural correct figures introduces an error which is, generally speaking, negligible, especially in view of the fact that the influence of the corrections themselves is often negligible.

The actual percentage of error introduced by the mechanical and manipulative sources of course depends upon the magnetic relief found in any given survey. Consequently it can not be stated. For average reconnaissance work with a sensitive setting (angle S approximately $1°$) the maximum error would be about 1½ to 2 scale divisions. More than this is seldom encountered in good field manipulation, although the anomalies range from 20 to 200 scale divisions.

MAGNETIC SOURCES OF ERROR

Certain irregular variations occur in the earth's magnetic field which sometimes achieve such proportions that they are called magnetic storms. These have nothing to do with rock formations. They can be detected by checking a hub station at intervals during the day. The same procedure by which diurnal variation is corrected out serves to correct out these irregular variations to some extent. If the check readings show too much disturbance, however, it is better to abandon the day's data.

FIELD PRACTICE

Inasmuch as a magnetic survey is merely a supplement to a geological survey, the field procedure must necessarily depend upon the geological problems to be solved. But certain general lines of attack are applicable to all problems.

The instrument is set near the center of the area to be surveyed or in some spot believed to be magnetically normal. This station becomes the datum plane to which the whole survey is referred just as sea-level is a topographic datum plane. The instrument reading at this point is arbitrarily established. Each morning the instrument is set at this station and allowed to become acclimated. During this process the temperature coefficient can be checked. Then the survey is carried out from this point, spacing the stations at any desired interval. The original station is revisited about three times during the day, and is the last station at night. For extensive work the hub station can be shifted as the survey proceeds, to avoid returning to a distant station.

The notes are then corrected for temperature, and the corrected values of the hub station are plotted on cross-section paper, with time as the abscissa and instrument reading as the ordinate. This shows the departures from the established base value in their relation to the time

of day. It is assumed that these departures are gradual so that the curve drawn through the plotted points represents the correction curve. This is, of course, an approximation. This correction curve, referred to the same base each day, automatically takes care of (1) diurnal variation, (2) day-to-day variation, (3) any mechanical variation, and (4) the correction to base.

On the base map on which are located the stations, lines of equal-latitude correction are drawn normal to magnetic north and the values placed on the lines. Thus the latitude and longitude corrections can be made simultaneously for each station.

All values are in terms of instrument scale divisions because the absolute C. G. S. units are unnecessary in work where only relative values have significance. It is possible, however, to reduce the scale-division values to approximate gamma values.

The foregoing procedure makes *a single operator* absolutely independent of any laboratory. In fact, in one small Kennedy fishing kit he can carry two instruments, repair tools, spare parts, drafting supplies, and map paper enough to isolate himself in a foreign inaccessible country for an indefinite time without sacrificing the quality of his work.

The area which can be covered depends upon the accessibility of the country and the spacing of the stations. In mountainous Arizona country the writer occupied 215 stations in 7 consecutive hours. The stations were 30 feet apart. Seventy-six stations per day at 1-mile intervals have been occupied by the writer. All corrections for an average day's field work can be made in from 1 to 2 hours.

EXAMPLES OF APPLICATION

Any magnetic instrument is merely a tool for the use of the geologist and engineer, and its success depends upon the skill with which it is used. The development of different geophysical methods has placed in his hands an array of tools like the array which a skilled sculpter finds before him. Part of his success depends upon his care in choosing the right tool for the right place. It is therefore necessary for him to know what each tool will do. Magnetic instruments may be looked to for the following services.

1. To locate *directly* certain deposits of such natural resources as iron, pyrrhotite, salt, nickel, *et cetera.*

2. To locate *indirectly* certain deposits of such natural resources as gold, platinum, and tin in placers, and ores associated with veins, dikes, sheets, contacts, *et cetera.*

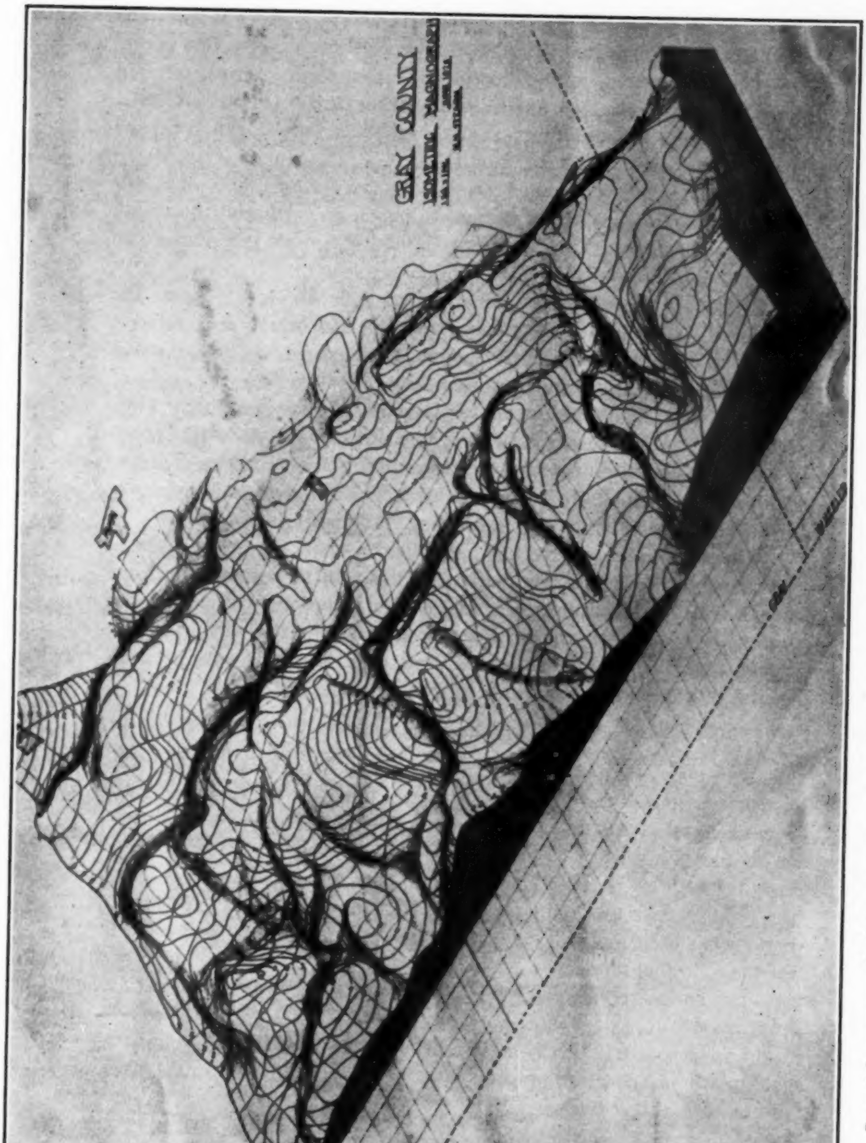


FIG. 7.—Isometric magnograph of Gray County. One square = 1 square mile. Contour interval, 5 instrunent scale divisions, Hotchkiss Superdip.

3. To do rapid reconnaissance work in advance of other geophysical instruments.

4. To locate geological features such as faults, folds, buried ridges, metamorphic changes, *et cetera*.

In all these types of service the Hotchkiss Superdip has already demonstrated its potentialities. A few specific examples in connection with oil exploration may be of special interest.

In Kansas the known "shoestrings" were found to be traceable by virtue of a diamagnetic reaction giving a magnetic "low." In Illinois a faint suggestion of the LaSalle anticline was obtained magnetically. In Arkansas the extension of the Ouachita Mountain uplift has been traced out under the Gulf Coastal Plain. In western Oklahoma the Beckham County fault is a decided magnetic feature, and certain of the structures in the Quartermaster red beds seem cored with paramagnetic rock formations, suggesting that they reflect deep-seated rather than mere surface structures.

In the Panhandle of Texas the buried extension of the Wichita Mountains has been traced across three counties. As the topography of these buried mountains seems to be reflected by the structure of the Big lime and to control the deposition of the so-called "granite wash," that topography is an important factor in oil exploration in the Panhandle due to the fact that the "Big lime" and the "granite wash" are the producing formations. In the developed areas the magnetic anomalies have been shown to reflect, qualitatively, the topography of those buried mountains. Consequently there is an important connection between oil exploration and magnetics. Figure 7 shows an isometric magnograph of Gray County in the Panhandle of Texas, drawn with the idea of bringing out the magnetic relief to show the character of the buried topographic features. The contour interval is 5 instrument scale divisions. The 1,100 stations for this magnograph are at approximately 1-mile intervals. Certain areas inaccessible by car were reached on foot. The field work required 27 man-days and the office work 5 man-days. The southern part of this area is still almost entirely unexplored by drilling.

USE OF MERCURY FOR DETERMINATION OF VOLUME OF ROCK SPECIMENS IN RUSSELL POROSITY APPARATUS[1]

W. B. GEALY[2]
Pittsburgh, Pennsylvania

ABSTRACT

A method is described wherein mercury is used in porosity determinations to measure the volume of the rock chunk. Inasmuch as mercury does not enter the pores of a consolidated rock, it is not necessary to dip the specimen in paraffin. The volume is measured in a Russell porosity apparatus, mercury, rather than acetylene tetrachloride, being used. The use of mercury saves time and eliminates the error of estimating the outer surface of the specimen. Comparisons with results obtained by dipping the specimen in paraffin and weighing in water show that the method is quite accurate.

INTRODUCTION

The essential feature of the method here proposed is the substitution of mercury for acetylene tetrachloride in the Russell porosity apparatus because of the advantage in not wetting the specimen. The determination of the porosity of a rock includes the measurement of two values: (1) the volume of the rock as a whole, and (2) the volume of the grains. The total volume of pore space is then found by subtracting the volume of the grains from the volume of the chunk. This paper is concerned only with the measurement of the first of these two values, namely, the volume of the rock chunk.

The writer acknowledges with pleasure the valuable suggestions offered by A. E. Ruark, R. E. Somers, and R. H. Johnson during the preparation of the manuscript.

APPARATUS

The apparatus used by the writer is shown in Figure 1 and is, with the exception of the wire basket, the one which was designed by W. L. Russell.[3] It is made of glass and is approximately 55 centimeters in

[1]Presented before the Association at the Fort Worth meeting, March 22, 1929. Manuscript received by the editor, March 14, 1929.

[2]3306 Iowa Street.

[3]W. L. Russell, "A Quick Method for Determining Porosity," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 10, No. 10 (October, 1926), pp. 931-38.

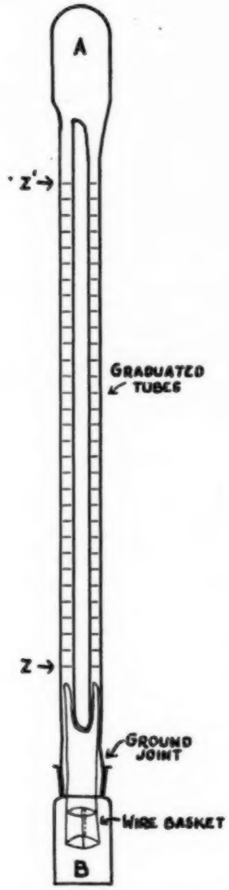


FIG. 1.—The Russell porosity apparatus with wire basket in place.

length. In Figure 1, *A* is the upper chamber, *B* the lower chamber with ground joint and wire basket, the two chambers being connected by tubes which are graduated to .05 cubic centimeter. The apparatus is so constructed that the upper chamber, when filled to the zero point *Z'*, has a capacity equal to that of the lower chamber, when the latter is filled to zero point *Z*. In practice, particularly when the wire basket is

used, these two chambers do not have exactly the same capacity, and the correction for the zero point must be found before measurements are made. When the wire basket is used, the correction is always negative, that is, it must be subtracted from the volume of the rock as read on the graduated tubes.[1] It has been found that the use of cross-section paper as a guide in reading the graduations on the tubes enables one to get more accurate results.

DETERMINATION OF THE CORRECTION FOR THE ZERO POINT

Before the volume of a rock chunk can be measured, it is necessary to know the correction for the zero point. This value is determined in the following way. Chamber *B* is removed, the apparatus inverted, and chamber *A* filled with mercury to a point a little above the zero point Z', the exact volume being read on the graduated scale. Then the wire basket is inserted, chamber *B* fitted over the tubes, and the apparatus rotated to an upright position; the volume of mercury in the apparatus is read on the graduated tubes. The pressure of the mercury will ordinarily open the ground joint unless the apparatus is held firmly together. However, the effect of heat from the hands is extremely slight because of the small amount of time consumed in taking the reading. The difference between the first and second readings is the correction for the zero point which, as previously stated, is always negative. After the zero-point correction is once accurately determined, this step may be omitted in succeeding measurements of the volume of the rock chunk.

MEASUREMENT OF THE VOLUME OF A ROCK CHUNK

The measurement of the volume of a rock chunk by this method is very simple. It is only necessary to handle the apparatus gently in order to prevent the breaking of the glass by the mercury. The sample is first cleaned thoroughly and weighed. The apparatus is inverted and chamber *A* filled to the zero point, or a little above, with mercury, the exact volume being read on the graduated tubes. After the volume reading (called Z') is recorded, the wire basket with the specimen is inserted into the upper end of the apparatus and chamber *B* attached to the greased ground joint. The apparatus is then rotated to an upright position and shaken slightly to dislodge any air bubbles that might have been caught around the rock. The reading (called R') on the grad-

[1]The wire basket was not a part of the original Russell apparatus, but has been used by the writer to insure complete immersion of the specimen in the mercury, which, under ordinary conditions, would push the rock up into the neck of chamber *B* and thereby introduce an error.

uated tubes is taken immediately in order to prevent any error which might be produced by a change in the temperature of the mercury due to the handling of the apparatus. The temperature at which the last reading is taken should be recorded if it is desired to calculate the density of the rock. The volume of the rock chunk is then found by subtracting the Z' reading from the R' reading corrected for the difference in the capacities of chambers A and B.

ADVANTAGES OF THE MERCURY METHOD

The principal advantages of the mercury method are three in number.

1. *Reduction of the time required to measure the volume.*—The use of mercury as the measuring liquid makes the total time required for the measurement of the volume as short as could be desired. This liquid drains completely and rapidly so that the readings can be taken without delay. Neither is any time lost in preparing the sample for the test, it being only necessary to brush the loose particles of rock from the specimen. The entire operation as described above requires ten minutes for completion and the specimen may be used immediately for the determination of the volume of the grains.

2. *Elimination of the error of estimating the position of the outer surface of the specimen.*—If, when the volume of a rock is measured, the inner surface of the surrounding liquid or solid does not correspond exactly with the outer surface of the sample, the results will not be accurate. In the acetylene tetrachloride method the liquid enters the pores of the rock, and the position of the outer surface of the specimen must be estimated. Also, when the sample is coated with paraffin, there is sometimes an error because the paraffin may enter the pores in unequal amounts or it may not completely surround the rock. The error produced by these two methods is reduced to a minimum by the mercury method. Mercury does not wet the rock and does not, in general, enter the pores, but it certainly surrounds the outer surface completely, thereby giving a true volume.

3. *Reduction of the temperature factor.*—Any error due to changes in temperature of the apparatus will, if present, be very small. Since the coefficient of volume expansion of mercury is small, and since the second reading is taken soon after the first, any temperature changes would have to be rapid to affect the results.

DISADVANTAGES AND LIMITATIONS OF THE MERCURY METHOD

The chief disadvantage of the method is that the mercury becomes dirty from exposure to the atmosphere and from contact with the rocks.

The latter factor may be substantially reduced by carefully cleaning the specimen before it is tested. Occasionally, therefore, clean liquid must be poured into the apparatus to replace the mercury that has become contaminated. If a supply of liquid sufficient for two or three fillings of the apparatus is kept on hand, a delay in the work is prevented and the dirty mercury may be cleaned at leisure. The dirty mercury can be cleaned several times by simply squeezing it through two or three thicknesses of clean cloth, but, eventually, it must be sprayed through dilute nitric acid to effect a complete cleaning. However, the time consumed in cleaning the liquid is but a small part of the time saved by using this method.

The writer has successfully used this method to measure the volume of several rocks which were so soft that they could be crumbled in the hand, but most of his work has been with fairly hard samples.

ACCURACY OF THE MERCURY METHOD

In order to obtain an idea of the accuracy of the method, the percentage of total pore space was determined for twenty-four rocks of various types. The porosity was calculated from the formula $P = 100 \dfrac{V - V_g}{V}$, where $V =$ the volume of the rock chunk, and $V_g =$ the volume of the grains. The volume of each rock chunk was determined twice, once by the mercury method and once by the Melcher method.[1] One value for the volume of the grains, determined by the pycnometer method, was used in computing the porosity of each sample. The possible error of the results was also calculated. In the mercury method the principal error is due to the inability to read the apparatus accurately. In the determination of the volume of the aggregate this error amounts to approximately .01 cubic centimeter. In the Melcher method the significant error, introduced in coating the sample with paraffin, is not easily calculated because it varies with the volume and porosity of the specimen, and with the care exercised in dipping the sample in the paraffin. However, this error is ordinarily smaller than the one introduced in the mercury method. The error involved in the determination of the volume of the grains by the pycnometer method was regarded as being negligible. In Table I, column 2 gives the per cent porosity, with the possible error due to inaccuracy in reading, when V was determined by the mercury method; column 3 gives the porosity, with the possible

[1] A. F. Melcher, "The Determination of Pore Space of Oil and Gas Sands," *Trans. Amer. Inst. Min. Met. Eng.*, Vol. 65 (1921), p. 470.

error due to an irregularity in coating the sample with paraffin, when V was determined by the Melcher method.

TABLE I

COMPARISON OF THE RESULTS OF TWENTY-FOUR POROSITY DETERMINATIONS

Rock type	*Per Cent Porosity Mercury Method*	*Per Cent Porosity Melcher Method*
Gabbro	0.9 ± 0.3	1.3 ± 0.2
Gabbro	0.7 ± 0.5	1.3 ± 0.3
Granite porphyry	1.1 ± 0.4	0.4 ± 0.3
Granite	1.1 ± 0.2	1.3 ± 0.1
Granite	1.3 ± 0.4	1.1 ± 0.2
Granite	1.8 ± 0.3	1.5 ± 0.2
Granite	1.0 ± 0.3	1.4 ± 0.1
Granite	1.1 ± 0.5	1.7 ± 0.2
Granite	1.1 ± 0.2	0.4 ± 0.2
Gneiss	1.1 ± 0.3	1.2 ± 0.2
Oil sand	16.2 ± 0.3	16.4 ± 0.1
Oil sand	17.0 ± 0.6	16.7 ± 0.3
Oil sand	13.1 ± 0.4	12.7 ± 0.2
Limestone	2.9 ± 0.3	2.9 ± 0.2
Limestone	1.2 ± 0.5	2.0 ± 0.3
Limestone	1.9 ± 0.3	1.9 ± 0.1
Limestone	1.1 ± 0.3	1.1 ± 0.1
Limestone	1.2 ± 0.4	1.1 ± 0.2
Limestone	1.2 ± 0.4	1.5 ± 0.2
Limestone	3.0 ± 0.3	3.4 ± 0.2
Limestone	1.6 ± 0.4	1.0 ± 0.2
Gray shale	17.1 ± 0.5	16.8 ± 0.2
Red shale	23.7 ± 1.1	22.9 ± 0.5
Red shale	12.7 ± 0.3	11.8 ± 0.1

An examination of the table shows that the mercury method is accurate within reasonable limits. The error of reading is a fairly high percentage of the porosity when the latter is small, but when, as is ordinarily true in oil sands, the porosity is greater, the error is correspondingly a smaller percentage. An error of .3 per cent in the porosity would make only a very small error (approximately .1 per cent) in the value computed for the density of the rock.

CONCLUSION

In conclusion, it may be said that the mercury method for the determination of the volume of a rock chunk is more rapid than the acetylene tetrachloride or Melcher method, that the results do not differ greatly from those obtained by the Melcher method, and finally, that it can be used for as wide a range of rock types.

GEOLOGICAL NOTES

CORRELATION OF THE BROWNSTOWN (RESTRICTED) FORMATION OF ARKANSAS*

On September 10, 1926, the U. S. Geological Survey issued a *Press Bulletin* on the "Oil-Bearing Formations of Southwestern Arkansas." In this bulletin the Brownstown, Ozan, Annona, and Marlbrook are correlated with the typical Taylor marl of Texas, and the Tokio formation with the Bonham and Blossom formations of northeast Texas and the Austin chalk of central Texas.

In Volume 11, Number 1 (January, 1927), of this *Bulletin* there appeared "Notes on the Stratigraphy of the Upper Cretaceous Formations of Texas and Arkansas," by L. W. Stephenson, in which that author made correlations as given in the previously mentioned press report.

Several years ago the writer agreed to describe the Upper Cretaceous ostracods of Arkansas, and a number of samples were submitted to him by W. C. Spooner. This resulted in a paper now in the press of the Arkansas Geological Survey entitled "Introduction to the Upper Cretaceous Ostracods of Arkansas." In this paper samples containing an ostracod and formainifer assemblage similar to that found in samples of Bonham clay were considered as Tokio, following the previously cited correlations. The few samples labelled Brownstown were poor in micro-fossils and the writer considered this to be the true condition. After that paper had gone to press, samples which Spooner called Brownstown were submitted to the writer and called Tokio by him, because they contained the Bonham clay fauna.

This divergence of opinion led Stephen H. Rook, James Kissling, and the writer to run a plane-table traverse across the upper part of the Tokio and the Brownstown to the base of the Ozan (Buckrange sand) from the area northwest of Ben Lomond to Brownstown, Arkansas.

It was found that the Tokio included no calcareous joint clays containing the Bonham clay micro-assemblage, but, on the contrary, contained only a few arenaceous foraminifers in its noncalcareous clays. On the other hand, the samples from the Brownstown (restricted) yielded a plentiful micro-assemblage, similar to that occurring in the Bonham clay of northeast Texas.

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It was also found that the ostracods incorrectly listed in the writer's paper previously mentioned as from the Tokio, occur throughout the Brownstown in association with those correctly listed as occurring in the Brownstown. The meager number of micro-organisms in the known Brownstown samples first considered was probably due to the action of sulphate waters which deposited a considerable quantity of selenite in the clay from which they were collected, and evidently removed by solution most of the contained micro-fossils.

From the foregoing it follows that the Brownstown (restricted) is to be correlated with the Bonham clay of northeast Texas, and the Austin of central Texas. Further confirmation is the fact that samples collected by Charles Rankin from the Eutaw (Tombigbee member) of Mississippi (correlated with the Austin by Stephenson[1] contain the same foraminifers and ostracods. Also the Buckrange assumes its correct importance as a basal sand, and it seems possible that the Tokio is equivalent to the Eagle Ford formation of Texas.

MERLE C. ISRAELSKY

SHREVEPORT, LOUISIANA
May 7, 1929

[1] *North Carolina Geol. and Econ. Survey*, Vol. 5 (1923), Pl. 8.

DISCUSSION

MASJID-I-SULAIMAN OIL FIELD, PERSIA
GYPSUM FLOWAGE IN PERSIA

H. G. Busk's *Earth Flexures*, reviewed elsewhere in this *Bulletin*, gives cross sections of the Masjid-i-Sulaiman (Temple of Solomon) oil fields of Persia (including the Maidan-i-Naphtun, Maidan-i-Naphtek, and Maidan-i-Bibian pools). So rarely are actual sections of Eurasian oil fields published that this one has been copied and is reproduced as Figure 1. It illustrates "mushroom structures" (Busk) due to flowage of gypsum somewhat analogous to the flowage of salt in salt domes. The writer believes that the same type of structure is present in Paradox Valley and other gypsum-filled valleys of western Colorado and eastern Utah.

Busk cites numerous examples of salt domes in Persia and in islands along the Bandar Abbas-Lingeh seaboard of the Persian Gulf.[1]

Gypsum flows readily. "All the great thrust sheets in Persia are composed almost entirely of what may be called by the analogy of its micro-structure 'gypsum quasi-schist'." So numerous are these sheets that Busk divides them, with reference to the altitude of the buried, rigid, oil-producing Asmari limestone into gamma, omega (fan folds), and iota structure from silimarity in section to these Greek letters. Figure 1 is a gamma structure, Figure 2 an omega structure.

No remarks are made by Busk about the oil accumulation in the principal oil field of Persia (Fig. 1), and the section indicates that the thinning of the lower Fars on the anticline is due to flowage rather than to the existence of a buried hill as postulated by the writer.[2] However, Nicolesco (*loc. cit.*) makes a positive assertion that there is evidence of an erosional unconformity on this and other similar anticlinal ridges in Persia and Iraq, and that the anticlinal crests were being denuded at the time of the incursion of the lower Fars highly saline sea.

A second phase of gypsum flowage is that the movements are still continuing. "Each advancing Lower Fars sheet is marked by an escarpment.... into which the consequent (streams) have incised themselves but little, and.... there is always a well-marked hanging valley system." Figure 2 is an example in which Ab-i-Shur River has cut a canyon 1,200 feet deep, only 10 feet wide at the bottom, and less than 200 feet wide at the top. In flood time the water forms a temporary lake 100 feet deep. Tembli River, near the Masjid-

[1]These salt domes (formerly explained by some writers as possibly buried hills) have been described by G. E. Pilgrim, *Memoirs Geol. Survey India*, Vol. 48, Pt. 2, 1924 (1926), K. Krejci, *Centralblatt für Min. Geol. u. Pal.* (1927), p. 287, R. K. Richardson, *Verh. naturhist.-med. Ver.*, Heidelberg, N. F. Bd. 15 (1926), C. P. Nicolesco, reviewed in this *Bulletin*, Vol. 13 (1929), p. 396.

[2]*Bull. Amer. Assoc. Petrol. Geol.*, Vol. 10 (1926), p. 422.

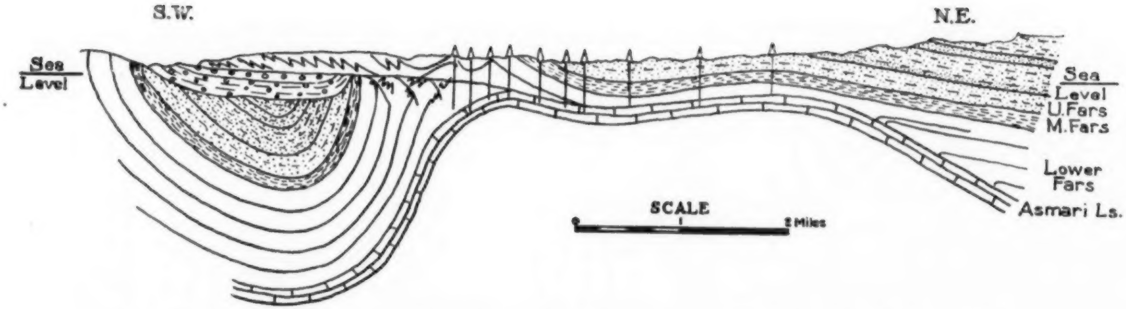

FIG. 1.—Cross section of the Masjid-i-Sulaiman oil field, Persia, showing the gypsum beds of the Lower Fars overriding nearly the whole of the foresyncline.

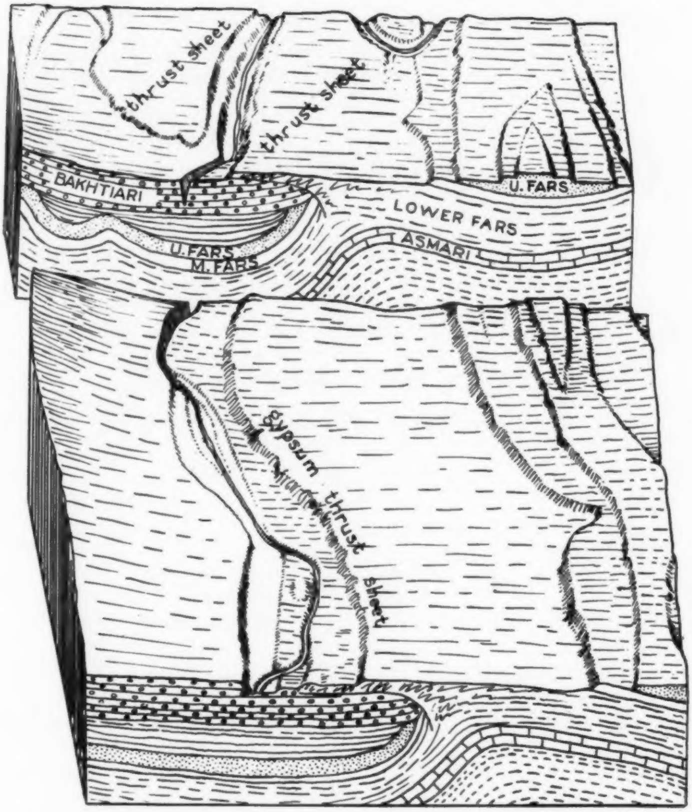

FIG. 2.—The Lani plain, southwestern Persia (center of diagram) with its gypsum thrust sheet flowing toward the Ab-i-Shur River canyon. The length of the figure is approximately 5 miles.

i-Sulaiman oil field, is cutting between "advancing fault walls (which) have approached one another to within a few hundred feet." In this manner gypsum has flowed as readily as salt from anticlines and the advancing sheets of gypsum have simulated anticlinal structure over synclines.

SIDNEY POWERS

TULSA, OKLAHOMA
May 4, 1929

CAP ROCKS OF OIL SANDS

E. McKenzie Taylor, School of Agriculture, Cambridge, England, is studying the influence of cap rocks of oil sands on the genesis of petroleum, and he would appreciate specimens of cap rocks from all parts of the world, in pieces weighing about 4 ounces. In a paper published in the *Journal of the Institution of Petroleum Technologists*, Vol. 14, No. 71 (December, 1928), pp. 825-40, entitled "The Bearing of Base Exchange on the Genesis of Petroleum," he concludes that "petroleum has resulted from the bacterial decomposition of organic matter, probably oils and fats, under the alkaline anaerobic conditions provided by shales containing sodium clay which has been subjected to hydrolysis in fresh water. The suggestion involves the assumption that all shales overlying oil-bearing strata have undergone base exchange and hydrolysis. From the geological evidence, the majority of the shales have undergone base exchange. It remains to be demonstrated that they have also been submitted to the second process—hydrolysis. It is hoped to collect and examine a large series of shales to determine whether alkalinity resulting from hydrolysis is a universal characteristic."

The origin of cap rocks of oil sands has been discussed by Mills and Wells in *U. S. Geol. Survey Bull. 693*, and by C. W. Washburne in *Trans. Amer. Inst. Min. Eng.*, Vol. 65 (1921), pp. 276 *et seq.* (with discussion).

SIDNEY POWERS

TULSA, OKLAHOMA
April 23, 1929

UNCONFORMITY AT TOP OF TRENTON IN LIMA, INDIANA, DISTRICT

In the article on the "Tectonic Classification of Oil Fields in the United States,"[1] the statement was made that the petroliferous horizon which has furnished the most oil in the Lima, Indiana, district is the Trenton formation and that in all probability it owes its porosity to solution. This implies an unconformity at the top of the Trenton and the basis for this assumption may be set forth briefly as follows. (1) The experienced drillers in this district soon found out that the good territory was characterized by what they called "crevices." Holes or openings were encountered by the drill which were in places only a foot or less in depth, but in places the tools dropped 6 or 8 feet, indicating cavities made by circulating underground water. (2) Many fragments blown from the wells by torpedoes showed honey-comb structure and examination of the walls of the cavities showed that they were produced by solution. (3) The depth at which production was encountered is suggestive. As a rule production was not found at the top of the limestone, but ordinarily at varying depths down to approximately 50 feet and only exceptionally below that depth. The producing level was not uniform, but varied greatly from well to well, as much as 50 feet in some offset locations. (4) The fact that gushers were found adjacent to small wells or dry holes also indicates that the cavities in which the

[1]This *Bulletin*, Vol. 13, No. 5 (May, 1929).

oil existed were more comparable with channels and openings produced by ground water than with openings produced by any other agency. (5) The distribution of oil and gas territory (as shown by the map opposite page 56 in Bownocker's report)[1] looks very much like a map of the underground caverns and channels in a region where we may now see the effects of ground water in thick limestone, for example, in the Mammoth Cave area of Kentucky.

One objection which might be raised to the assumption of an unconformity at the top of the Trenton is the regular thickness of the Trenton formation. To this objection the writer wishes to oppose the following three points. (1) It is a well known fact that in regions where underground water is at work channelling thick bodies of limestone, the highest topographic elevations may be located above places where erosion is most effective. In other words erosion by solution does not reduce the thickness of the rock mass affected, in the early stages of the process. (2) It is very doubtful whether anyone would be justified in reaching a conclusion about the thickness of the Trenton from the records of the wells which have penetrated the Trenton, because these wells are too few. Again, we have definite information from drillers which points to the conclusion that the top of the Trenton may be very irregular and that consequently the *thickness may vary considerably*. In Cass township of Hancock County, Ohio, Bownocker[2] reports the following abrupt changes in the top of the limestone. In a well in the northeast quarter of Section 22 the Trenton lies at 1,040 feet. The east offset (400 feet away) found it 127 feet lower, and a well on the west (one quarter of a mile distant) found it 67 feet lower, and a well on the south (at a similar distance) found it 75 feet lower. Whereas this "hogback," as the drillers called it, might be ascribed to structural conditions, yet the fact that it was characterized by very many "fissures" and was likely to "cave" makes the first explanation more plausible. (3) An interesting corroborative piece of evidence is furnished by Reeves.[3] Most of northwestern Ohio and northeastern Indiana is covered by a mantle of glacial drift. In a few areas near Wabash, Huntington, and Kentland in Indiana, however, the drift is thin or absent. There the outcrops of Ordovician rocks show the limestones standing at fairly high angles (up to 20°). Furthermore, the rocks differ considerably in age from place to place. These facts seem to indicate that diastrophism may have been much more intensive and effective during the latter part of the Ordovician period than we have generally believed or known. If that is granted, then it is not difficult to postulate changes in water and land distribution sufficiently great to produce unconformities.

WALTER A. VER WIEBE

WICHITA, KANSAS
May 10, 1929

[1]*Geol. Survey Ohio Bull.* 1, Fourth Ser. (1903).

[2]*Op. cit.*, p. 70.

[3]This *Bulletin*, Vol. 9, No. 2 (February, 1925), p. 322.

REVIEWS AND NEW PUBLICATIONS

"The Kevin-Sunburst and Other Oil and Gas Fields of the Sweetgrass Arch." By EUGENE S. PERRY. *State Bur. Mines and Metallurgy (Montana) Memoir 1* (December, 1928), 41 pp. including bibliography; 7 plates and 3 figs.

The Montana State Bureau of Mines and Metallurgy is to be congratulated on the appearance of its first memoir. This report on the Sweetgrass arch fields, although mimeographed, contains clear and well-printed maps and excellent photographs of material from the producing horizons.

The producing horizons are the Sunburst sand, the Madison lime, stray sands in the Ellis formation (Jurassic), and scattered dolomite beds of Devonian age. The author considers the so-called "stray sands" in the Ellis to be merely fractures, possibly caused by the collapsing of the very porous Madison limestone below. The Sunburst sand lies at the base of the Kootenai and has a very irregular thickness, ranging from 5 to 50 feet. In both the Sunburst and Madison "pays," production depends entirely on porosity and is practically independent of structure. In the Madison, the porosity is believed to be due to the action of circulating ground water while the Madison formed a land surface prior to the deposition of the Ellis formation.

The source of the oil is not definitely known, but the presence of solid bitumens on the old Madison land surface leads to the view that the oil has migrated upward and that some migration occurred before Jurassic time.

The latter half of the memoir deals with water conditions, operating conditions, and production statistics.

W. V. HOWARD

URBANA, ILLINOIS
April 19, 1929

"The Coral Reef Problem." By WILLIAM MORRIS DAVIS. *American Geographical Society Special Publication No. 9* (1928), 596 pp., 227 figs.

More than ninety years ago Charles Darwin, then a young man, explained the development of barrier reefs from fringing reefs and of atolls from barrier reefs by upgrowth on intermittently, slowly subsiding foundations, on which upgrowing reefs maintain their crests at sea-level. So convincing was Darwin's exposition of his theory of coral reefs that it gained universal acceptance and was not questioned for approximately thirty years. During the latter part of the nineteenth century, however, several alternate theories were proposed, and by the end of the century Darwin's theory was generally rejected.

The origin of barrier reefs and atolls has remained one of the many unsettled geologic problems. Professor Davis, after an extensive study of the problem, has confirmed Darwin's original theory of reef formation and his

comprehensive, lucid, and painstakingly thorough exposition of the subject will, in the opinion of the reviewer, leave little, if any, doubt as to the correctness of his major conclusions.

The present volume is a critical study of the various theories proposed to account for coral reefs, and the efficacy of the various theories when confronted with a vast array of facts. It is emphasized in the introduction that:

> Independent evidence as to the value of competing theories of reef origin can be best obtained not from the reefs themselves, but chiefly from the physiographic features of the coasts, either insular or continental, that are bordered by fringing reefs or fronted by barrier reefs; and also from the structure of elevated reefs. * * * The biology and especially the symbiosis of the reefs are unquestionably important subjects in themselves, but the opportunity for the establishment and growth of reefs is so largely determined by the physiographic conditions of insular and continental coasts, over which reef-building organisms have no control, that those physiographic conditions necessarily assume the leading rôle in the problem under discussion. (p. 3.)

The book is divided into two parts. Part I, entitled "The Leading Theories of Coral Reefs," contains a general description of the observable features of coral reefs and a critical study of the various theories advanced to account for them. Darwin's theory was based on the known limitation of reef-building activity to shallow depth, and was invented to explain the transformation of fringing reefs to barrier reefs and barrier reefs to atolls. Certain deducible consequences of the theory were recognized by Darwin, but others were not. Darwin recognized that barrier reefs and atolls, formed in accordance with his theory of subsidence, should possess great thicknesses and that they should possess characteristic internal structure. He recognized also that too rapid subsidence would drown an upgrowing reef and cited the submerged Chagos atoll in the Indian Ocean as evidence of such submergence. Dana, who followed Darwin by four years in investigating the coral reefs of the Pacific, showed that a subsiding island should have an embayed shore line and pointed out that islands encircled by barrier reefs actually do have embayed shore lines. Another independent verification of Darwin's theory is found by the author in that it affords an explanation for the disposal of the great amount of detritus that must have been removed from the maturely dissected islands. He shows that fringing reefs could not flourish coincidently with the active outwash of detritus from a lofty and rainy island, as the outwash material would soon smother the coral growth. He says:

> The disappearance of large volumes of detritus from maturely dissected islands and the development of barrier reefs around their non-cliffed but embayed shores, must therefore be accounted for in some reasonable manner in any competent theory of coral reefs. (p. 51.)

He shows how these conditions can reasonably be explained by subsidence during the detrital discharge.

The author shows further that as a consequence of Darwin's theory we must expect unconformable contacts between the eroded foundation masses and the reefs and lagoonal limestones. He finds confirmation of this in the relationship between elevated reefs and their eroded volcanic foundations.

In Chapter 4 the author presents and analyses nine alternative theories of reef formation in addition to an alternative offered by Darwin himself.

He finds that, although these theories explain, in general, the facts they were invented to explain, they do not explain other equally pertinent facts; therefore, all of them are untenable. Daly's theory of glacial control is reserved for a more extended discussion in Chapter 5. This the author considers as the only serious rival of Darwin's theory. Daly's theory is based on the general lowering of the ocean during glacial times. Coincident with this a general lowering of the temperature of oceanic water is postulated sufficient to inhibit coral growth which would permit abrasion by waves working at a depth of 30 or 40 fathoms below the present sea-level. The abraded platforms and benches thus formed furnished the foundation for present-day barrier reefs and atolls built up during the gradual rise of ocean level to its present stand in post-glacial time. The theory explains the nearly uniform depth of a large number of barrier reef and atoll lagoons on the assumption that they represent the slightly modified platforms on which the reefs and atolls were built. It demands a uniform stability of reef foundations throughout a long period of time. Davis found that the accordant depths of lagoons can be explained more logically by aggradation than as abraded platforms and that there is plentiful evidence of differential subsidence and emergence in the coral seas. He did find, however, that certain features on the northern and southern belts of the coral seas could best be explained by the lowering of the ocean level during glacial times and interruption of reef growth by the chilling of the water. Such interruption of reef growth, however, did not extend to the main central area of the coral seas.

In Chapter 6, the concluding chapter of Part I, Davis proposes a modification, or rather a supplement, to Darwin's theory, which he calls the theory of the marginal belts of coral seas. He distinguishes three belts of the oceans: the cooler seas, the islands of which have never been reef-protected; the coral seas, the islands of which are and have long been characteristically reef-protected; and the intermediate marginal belts, where reef growth was interrupted during glacial epochs. The characteristic physiographic features to be expected on stationary, rising, and subsiding islands and coasts in each of these three zones, and the deducible effects of changes of ocean level during glacial and post-glacial time on each of the nine types of islands thus theoretically possible are developed in this chapter.

With the various theories and deducible consequences of each theory clearly set forth in Part I, the author proceeds in Part II to present and analyze the facts gathered from his own observations and from an exhaustive study of the literature. Successive chapters are devoted to "The islands and banks of the cooler seas," "The marginal belts of the coral seas," "Reefless coasts in the coral seas," Reefless young volcanic islands in the coral seas," "Volcanic islands with plunging cliffs and embayed shore lines, with or without barrier reefs," "Embayed, fringing-reef islands without plunging cliffs or barrier reefs," "Embayed, non-cliffed islands with barrier reefs," "The small islands of almost-atolls," "Elevated fringing and barrier reefs," "Elevated almost-atolls and atolls," "Submerged reefs and banks in the coral seas," "The features of sea-level atolls." A final chapter is devoted to a "Review of conclusions drawn from the preceding chapters." The bibliography at the end of the volume contains 744 references.

In an early chapter (pp. 23-24) the author devoted a few paragraphs to "The nature of geological theories." He points out that:

> It is not enough that the theory in its simple initial form shall explain the facts that it was invented to explain; indeed, unless it is competent to meet that preliminary test, it should be discarded at once as worthless. It must do more: its additional elements, not perceived when it was invented, must be proved to be the true counterparts of additional facts not previously in mind, perhaps not then even discovered. The formulation of these additional elements of the theory is accomplished in geological investigation by the mental process of deduction, which, proceeding in a more orderly manner than invention, attempts to work out all the possible consequences of the theory, with particular attention to those consequences that may be to-day visible. Then these consequences, as clearly defined as may be, are to be confronted with the facts, old and new; if they survive this confrontation, the theory is confirmed. If the deduced consequences not only meet successfully all the facts that were known when the theory was invented and all the facts that are later found by wandering exploration, but if they serve also as guides to the discovery of new facts of a well specified kind, then the theory is particularly well recommended. It is still further strengthened if it makes possible the prediction of the occurrence of previously unknown facts.

The reviewer knows no more perfect application of the principles set forth in the paragraph quoted than in Professor Davis' volume on the coral reef problem. We have here a thorough deduction of the possible consequences, not only of one theory but also of several conflicting theories, and a confronting of each of the theories with a great mass of carefully ascertained facts. The result is a thoroughly convincing confirmation of Darwin's theory and the rejection as untenable of all conflicting theories.

E. RUSSELL LLOYD

MIDLAND, TEXAS
May 8, 1929

"Madagascar and Its Oil Lands." By ARTHUR WADE. *Jour. Inst. Petrol. Tech.* (London, February, 1929), pp. 1-33; illus.

In this excellent review of the geology of Madagascar the author points out that seepages are close to igneous intrusions and suggests that the petroleum has been distilled from carbonaceous matter by heat which emanated from the intrusives. There is no commercial production on the island, but the prospects for oil have not been condemned by adequate drilling.

SIDNEY POWERS

TULSA, OKLAHOMA
April 12, 1929

Earth Flexures. By H. G. BUSK. Cambridge University Press (Cambridge, England, 1929). Large octavo, 106 pp., illus. Price, 12 s. 6 d. net.

The full title of this book is *Earth Flexures, Their Geometry and Their Representation and Analysis in Geological Section with Special Reference to the Problem of Finding Oil.* The six chapters discuss definitions of folds and folding, geometrical construction of earth flexures in geological sections, the problem

of locating the axial plane of folds underground (assuring competent or parallel folds with no thinning of the section or unconformity), surface mapping, examples of Tertiary flexures in Burmah (asymmetrical steep-sided folds), in Persia (including gypsum thrust sheets), and in the eastern margin of the Gulf of Sinai (Rift valley structure).

For geologists working in steeply folded strata this is a very important book, because the failure to locate the axis of an asymmetrical anticline or complex structure at the horizon of the oil-producing stratum has led to many dry holes and condemnation of folds which may trap petroleum in parts not tested by the drill. Also, attention is called to their variable factors such as curved axial planes, disappearance of steep folds with depth, surficial gypsum anticlines far distant from deep-seated petroliferous anticlines. The text is accompanied by excellent illustrations and many geometric drawings.

A few definitions are given for the benefit of those who do not have access to this book:

The "axial" or "apical" plane of a fold is a surface so disposed within it that any point upon that surface is equidistant from either limb of the fold, as defined by any particular horizon.

The "apex" of a fold is the line of intersection between the axial plane and either that of the horizon or the ground surface.

The "crestal plane" of an anticline is a surface so disposed within it that it cuts any horizon in the fold along the line in which that horizon lies horizontally. The crestal plane rarely coincides with the axial plane, but often does so very nearly.

The "crest" of an anticline is a line at ground surface within the anticline, along which all horizons lie horizontally. The crest rarely coincides with the apex.

The "trough" of a syncline is a line within the syncline at ground surface, along which all horizons lie horizontally.

A review of the Persian examples is given under DISCUSSION, this *Bulletin*. The cross sections of Burmah oil fields do not show the oil sands, the producing area, or the actual control for the sections. Some of the clay members are attenuated by folding, but the deeper horizons are shown to be parallel.

In view of the evidence which is being accumulated, especially in the fields of North and South America, of disconformities or unconformities (buried hills in large part) at all producing horizons and of thinning of the stratigraphic section *on all producing anticlines* (partly published conclusion of Alex W. McCoy, with which the reviewer concurs), the geologists familiar with Burmah oil fields are asked by the reviewer to publish actual cross sections.

Rift valley structure, as known from surface geology, is described in detail with excellent illustrations of "crescentic" faults, "hinge" faults, and systems of *en échelon* faults. Oil has yet to be found in commercial quantities in this area.

SIDNEY POWERS

TULSA, OKLAHOMA
April 24, 1929

"Oil and Gas Development in Michigan." By R. B. NEWCOMBE. *Geol. Survey Division Pub. 37*, Geol. Series No. 31, Part III, Department of Conservation of Michigan (Lansing, 1929). 115 pp., 17 figs.

This bulletin is a most welcome addition to the literature dealing with the oil and gas possibilities of Michigan. The last bulletin on this subject

published by the Michigan Survey was Publication No. 14, Series 11, by R. A. Smith, which was published in 1912. Newcombe, in order to make a complete report, necessarily includes in his bulletin much of the general introductory material which was contained in the earlier publication, but most of it is devoted to the history, production, and geology of the Saginaw and Muskegon fields and the record of wildcat wells, which have been drilled as a result of the development of these fields. The subject matter is divided into nine parts: (1) introduction, (2) history, (3) stratigraphy, (4) formations containing oil and gas, (5) comparison of well sections, (6) structure, (7) Saginaw oil field, (8) explorations resulting from the Saginaw development, and (9) legislation concerning oil and gas.

In the introduction it is pointed out that "the only accumulations of oil and gas of any size in Michigan are governed by structural conditions." Since most of the state is covered by glacial drift, and subsurface control is remote, shallow test-hole drilling is suggested as practicable.

In the section on history, attention is called to the many showings of oil and gas, which were found by drilling in different parts of the state prior to the discovery of the present commercial production. Most important of these were the showings of oil and gas near Muskegon, Saginaw, Port Huron, and Allegan.

Under stratigraphy, formations of Cambrian, Ordovician, Silurian, Devonian, Mississippian, Pennsylvanian, and Pleistocene age are discussed. A geologic column is given from the Cambrian to the Pleistocene. The lithology, thickness, and distribution of each formation is described. Important, as regards exploration by shallow tests, is the amount of glacial drift. The thickness of the drift ranges from a mere veneer to 1,000 feet, and the average is given as 200 feet.

The Berea, Traverse, Dundee, Monroe, lower Salina, and Trenton formations are thought to offer the best possibilities for commercial production of oil and gas.

Two cross sections are shown—one taken across the central part of the basin and the other across the southern part of the state. These sections should prove of much value to those interested in prospecting for oil or gas. The most important features brought out by the sections are: (1) the thinning of the Traverse formation toward the south, and (2) the absence of the Berea sand and Sunbury shale in the western part of the state.

Newcombe states that:

> The structure of the Paleozoic rocks of Michigan has always been termed as that of a great basin. . . . It is now known that there are intensified lines of folding of considerable length and that minor structures of significant magnitude exist within the center of the basin.

The author is to be commended on his excellent and thorough discussion of the Saginaw field. This discussion takes up the history, scope of the field, record of producing properties, production, and geologic conditions. Three type well logs are given.

In the section on "Exploration resulting from the Saginaw development," the state is divided into the following parts or districts: Saginaw County, southeast of the city of Saginaw, southwest of the city of Saginaw, Port Huron

district, and the Thumb region, southeastern district, central Michigan, southwestern Michigan, western Michigan, northern lower Michigan, and the northern peninsula. In the Saginaw district, two wells drilled on "structures" mapped from coal records proved that coal data in this area can not be relied upon for structure mapping. Type well logs are given for all of these districts. There are five subsurface structure maps, as follows: (1) the Deerfield anticline and contours of elevation of the Trenton limestone in southeastern Michigan and southern Ontario, (2) a progress structural contour map of southeastern Michigan, with contours drawn on top of the Berea, (3) a structure contour map of southwestern Michigan, and (4) two maps of the Muskegon anticline, as contoured on the red horizon in the Coldwater shale and on top of the Traverse formation.

As a result of the stimulus given wildcatting by the discovery of commercial production at Saginaw, two other fields have been found, the Muskegon field near Muskegon in the western part of the state, and the field opened by The Pure Oil Company in western Midland County. In central Michigan, along the Howell-Owasso anticline, the Sun Company and Norris and Smith found some oil in the Traverse formation, though not in paying quantities.

The Muskegon field is discussed as to history of development, scope of field, production, and geologic conditions. A cross section is given, based on well-log correlation across the field. The discovery well at Muskegon was drilled in December, 1927. Production is from the Traverse and Dundee formations of Devonian age.

In the section on legislation concerning oil and gas, Act No. 65, dealing with oil and gas wells, is given in complete detail. This Act requires the filing of a written application for a permit to drill, and makes compulsory the proper plugging of wells.

The bulletin by Newcombe fills a long-felt need for a review of the development which has been accomplished in the state of Michigan since the issuance in 1912 of Publication 14 by R. A. Smith. The bulletin will be of great value to anyone contemplating exploration for oil or gas in Michigan.

CHARLES G. CARLSON

TULSA, OKLAHOMA
May 9, 1929

ABSTRACT

"Origin of the Color of Red Beds." By GEORGE E. DORSEY. *Jour. Geol.*, Vol. 34, No. 2 (February-March, 1926).

It is shown that the color is not due to a larger iron content, nor to the mere presence of ferric oxide. It is the presence of red ferric hydrate (turgite), and ferric anhydrite (hematite) which makes the rocks red.

Conditions under which dehydration of ferric oxides can occur are to be investigated rather than conditions producing ferric oxide. The conditions producing ferric oxide are the ordinary erosional processes. The indisputable evidence that the red beds are continental in origin explains why red rocks

retained their color, since the sediments were never exposed to the reducing action of the marine continental shelves.

The red beds occur *in situ*, where they were formed as soil; they were not transported. Red soil is formed to-day in warm, moist climates, where vegetation prevents removal, yet drainage is active,—not in swamps, else decaying vegetable matter would cause reduction and greenish rocks would result. Alternating wetting and drying, and active drainage are powerful oxidizing agencies, and quickly burn up organic material.

ROBERT H. DOTT

TULSA, OKLAHOMA
April, 1929

RECENT PUBLICATIONS

ALASKA

"The Skwentna Region, Alaska," by S. R. Capps. *U. S. Geol. Survey Bull. 797-B*. Pp. 67-98, Pl. 1, Fig. 1. Supt. of Documents, Washington, D. C. Price, $0.15.

"Aerial Photographic Surveys in Southeastern Alaska," by R. H. Sargent and F. H. Moffit. *U. S. Geol. Survey Bull. 797-E*. Pp. 143-60, Pls. 4-5, Figs. 3-4. Supt. of Documents, Washington, D. C. Price, $0.15.

"Geology and Mineral Resources of the Aniakchak District, Alaska," by R. S. Knappen. *U. S. Geol. Survey Bull. 797-F*. Pp. 161-227, Pl. 6. Supt. of Documents, Washington, D. C. Price, $0.20.

ARKANSAS

"The Fauna of the Middle Boone near Batesville, Arkansas," by G. H. Girty. *U. S. Geol. Survey Prof. Paper 154-B*. Pp. 73-103, Pls. 9-12. Supt. of Documents, Washington, D. C. Price, $0.15.

AVIATION

The Black Hills Engineer, Vol. 17, No. 2 (March, 1929), South Dakota State School of Mines, Rapid City. Special number on aviation (photography, commercial mining, mapping, forestry, medicine, mail). Pp. 73-153, illus. Price, $1.00.

CALIFORNIA

"Oil Shale in a Producing Oil Field in California," by H. W. Hoots. *U. S. Geol. Survey Prof. Paper 154-E*. Pp. 171-73, Pl. 17. Supt. of Documents, Washington, D. C.

CANADA

"Oil Prospects Near Bragg Creek, Alberta," by G. S. Hume, pp. 1-20; "Stratigraphy, Stucture, and Clay Deposits of Eastend Area, Cypress Hills, Saskatchewan," by F. H. McLearn, pp. 21-53; "Deep Borings in the Prairie Provinces and North West Territories," by E. D. Ingell, pp. 81-90; *Geol. Survey of Canada Summary Report*, 1927, Pt. B (Ottawa, 1928).

COLOMBIA

Boletin de Minas y Petroleos, Vol. 1, No. 2 (February, 1929), Ministerio de Industrias, Bogota, Colombia. Contains chapters on laws governing concessions, technical papers, and foreign items. Pp. 82-160.

CROOKED HOLES

"Acid Bottle Method of Surveying Holes," by H. M. Harris. *Oil Weekly* (May 3, 1929), pp. 47-48; 3 figs.

"Straight Drilling of Rotary Holes," by R. D. Elliott. *Oil and Gas Journal* (May 9, 1929), p. 49.

"How to Drill a Vertical Well; Speed Must Be Secondary," *Oil and Gas Journal* (May 9, 1929), pp. 49 and 191.

"Weight Indicator Solves Many Drilling Problems," by Wallace Davis. *Oil Weekly* (March 8, 1929), p. 23; illus.

"Crooked Holes—Causes and Effects," by Frederic H. Lahee. *Oil Weekly* (March 29, 1929), pp. 29-40. *Oil Weekly* (April. 5, 1929), pp. 27-34, 78-88; 33 figs.

"Overcoming Crooked Holes," by Harvey C. Hardison and W. W. Warner. *Oil Weekly* (April 12, 1929), pp. 49, 96.

"A Seismic Method of Determining the Deviation of Drill Holes," by Mark C. Malamphy. *Oil Weekly* (April 26, 1929), pp. 31-32, 70, 73-74, 76, 78, 80; 2 figs.

"Drilling Contractor Develops Methods of Keeping Holes Straight," by John Power. *National Petroleum News* (April 10, 1929), pp. 63, 65, 67; 1 fig.

"Crooked Holes Next Important Problem," by Frederic H. Lahee. *Oil and Gas Journal* (March 28, 1929), pp. 38, 150-52; 3 figs.

"Frequent Surveys Check Crooked Hole," by Harvey C. Hardison and W. W. Warner. *Oil and Gas Journal* (April 4, 1929), pp. 104, 191-92.

"Heavy Penalties of Crooked Hole," by Joe H. Russell. *Oil and Gas Journal* (April 4, 1929), p. 104.

"Pioneers Had Crooked Hole Problems," by H. B. Goodrich. *Oil and Gas Journal* (April 4, 1929), pp. 109, 220, 222.

"Cause and Effect of Crooked Holes," by D. R. Snow. *Oil and Gas Journal* (April 4, 1929), pp. 109, 218; 1 fig.

"New Invention Designed to Show Hole's Deviation from Vertical," by Thomas F. Smiley. *Oil and Gas Journal* (April 25, 1929), pp. 44, 150-51; 1 illus.

GEOPHYSICS

"Geophysical Methods of Prospecting; Principles and Recent Successes," by C. A. Heiland. *Colorado School Mines Quart.* (Golden, Colorado, March, 1929). 163 pp., 66 figs. Price, $1.00.

"Graphical Terrane Correction for Gravity Gradient," by Donald C. Barton. *U. S. Bur. Mines Tech. Paper 444* (1929). 12 pp., 7 figs. Supt. of Documents, Washington, D. C. Price, $0.10.

MICHIGAN

"Oil and Gas Development in Michigan," by R. B. Newcombe. *Michigan Geol. Survey Geol. Series 31* (1928). 299 pp., 17 figs.

MONTANA

"The Northward Extension of the Sheridan Coal Field, Big Horn and Rosebud Counties, Montana," by A. A. Baker. *U. S. Geol. Survey Bull. 806-B.* Pp. 15-67, Pls. 6-29, Figs. 2-9. Supt. of Documents, Washington, D. C. Price, $0.45.

"Thrust Faulting and Oil Possibilities in the Plains Adjacent to the Highwood Mountains, Montana," by Frank Reeves. *U. S. Geol. Survey Bull. 806-E.* Pp. 155-95, Pl. 44, Figs. 13-19. Supt. of Documents, Washington, D. C. Price, $0.10.

PERU

Geologie von Peru, by G. Steinmann. Carl Winters Universitätsbuchhandlung, Heidelberg, Germany. 448 pp. with geologic map in colors. Price, bound, 32 M.

TENNESSEE AND VIRGINIA

"The Age and Stratigraphy of the Chattanooga Shale in Northeastern Tennessee and Virginia," by Joel H. Swartz. *Amer. Jour. Sci.* (May, 1929), pp. 431-48; 3 figs.

TEXAS

The A. A. P. G. Permo-Carboniferous Research Committee, of which R. C. Moore is general chairman and F. B. Plummer is chairman for Texas, working under the auspices of the Society of Economic Paleontologists and Mineralogists, has prepared the following geologic maps in coöperation with the Bureau of Economic Geology, University of Texas. The combination map includes Nolan, Fisher, Jones, Taylor, Kent, Stonewall, Haskell, Throckmorton, Dickens, King, Baylor, Knox, Motley, Cottle, Foard, Wilbarger, Hall, Hardeman, and Childress counties. The maps may be obtained from the Bureau of Economic Geology, Austin, Texas.

County	*Size in Inches*	*Scale*	*White Paper Print*	*Cloth Print*	*Paper Print Hand-Colored*
Parker	46×46	4,000ft. = 1in.	$2.00	$3.00	$4.00
Palo Pinto	47×51	4,000ft. = 1in.	2.00	3.00	4.00
Stephens	45×46	4,000ft. = 1in.	2.00	3.00	4.00
Shackelford	46×46	4,000ft. = 1in.	2.00	3.00	4.00
Stonewall	46×46	4,000ft. = 1in.	2.00	3.50	4.00
Wichita	37×47	4,000ft. = 1in.	2.00	3.00	4.00
Coleman	47×64	4,000ft. = 1in.	2.25	4.00	4.50
Combination	42×64	5 mi. = 1 in.	1.25	3.50	3.50

THE ASSOCIATION ROUND TABLE

MEMBERSHIP APPLICATIONS APPROVED FOR PUBLICATION

The Executive Committee has approved for publication the names of the following applicants for membership in the Association. This does not constitute an election, but places the names before the membership at large. If any member has information bearing on the qualifications of these applicants, please send it promptly to J. P. D. Hull, Business Manager, Box 1852, Tulsa, Oklahoma. (Names of sponsors are placed beneath the name of the applicant.)

FOR ACTIVE MEMBERSHIP

Judson Lowell Anderson, Maracaibo, Venezuela, S. A.
E. C. Reed, William H. Spice, Jr., J. B. Burnett

James M. Hamill, Los Angeles, Calif.
James L. Tatum, Donald D. Hughes, R. D. Reed

Bond Delbert Jones, Abilene, Tex.
P. A. Meyers, H. G. Daniels, Charles L. Renaud

John A. Kay, Wichita Falls, Tex.
Wallace C. Thompson, I. R. Sheldon, C. W. Clark

N. P. Larsh, Fort Worth, Tex.
Wesley G. Gish, H. Smith Clark, D. D. Christner

Clarence A. Russell, San Angelo, Tex.
Cary P. Butcher, R. E. Rettger, P. R. Yewell

Merrill A. Stainbrook, Lubbock, Tex.
W. I. Robinson, L. T. Patton, A. C. Trowbridge

Olaf F. Sundt, Houston, Tex.
J. P. Schumacher, W. F. Henniger, Marcus A. Hanna

Wilhelm Wunstorf, Berlin, Germany
F. Julius Fohs, Louis Roark, Sidney Powers

FOR ASSOCIATE MEMBERSHIP

Merritt H. Brown, Tulsa, Okla.
Charles E. Decker, V. E. Monnett, A. J. Williams

Irwin C. Colman, Columbus, Ohio
Edmund M. Spieker, F. P. Vickery, A. J. Tieje

Charles S. Conrad, Wichita Falls, Tex.
I. R. Sheldon, M. M. Garrett, C. W. Clark

Louis J. Fulton, Chickasha, Okla.
Clyde M. Becker, Charles E. Decker, Roger W. Sawyer

Worth C. Gibson, El Dorado, Kan.
Marvin Lee, John S. Barwick, C. R. Thomas

Kenneth Paul Hedges, Tulsa, Okla.
Robert Wesley Brown, L. B. Snider, Elfred Beck

Elizabeth Alice Isaacs, Bartlesville, Okla.
W. L. Walker, J. M. Nisbet, Hugh McClellan

Howard C. Pyle, Los Angeles, Calif.
H. W. Hoots, Desaix B. Myers, E. B. Noble
Stephen Gose Waggoner, Wichita Falls, Tex.
C. W. Clark, Thornton Davis, M. M. Garrett
Karl Louis Walter, Wichita Falls, Tex.
C. O. Nickell, C. W. Clark, F. C. Sealey
Gerald D. Young, Bartlesville, Okla.
E. F. Schramm, J. M. Nisbet, E. E. Lindeblad

FOR TRANSFER TO ACTIVE MEMBERSHIP

Martin W. Baden, Winfield, Kan.
A. W. McCoy, F. L. Aurin, K. C. Heald
Everett L. Bradley, Amarillo, Tex.
Harry E. Crum, J. J. Maucini, C. Max Bauer
Edmund F. Estergren, Fort Worth, Tex.
C. W. Clark, M. M. Garrett, Thornton Davis
Eugene B. Germany, Dallas, Tex.

Baker Hoskins, Jr., Laredo, Tex.

William F. Knode, Jr., DeNoya, Okla.

Karl A. Schmidt, Fort Worth, Tex.
J. Earle Brown, J. H. Jenkins, H. B. Fuqua
James R. Seitz, Wichita Falls, Tex.
C. W. Clark, F. C. Sealey, Thornton Davis
Joseph J. Zorichak, Casper, Wyo.

EXECUTIVE COMMITTEE AT TULSA, MAY 7, 1929

The executive committee met at Association headquarters, Tulsa, May 7, 1929, with the following members present: president, J. Y. Snyder of Shreveport; past-president R. S. McFarland of Tulsa; second vice-president A. R. Denison of Fort Worth; and third vice-president F. H. Lahee of Dallas.

1930 Convention—New Orleans was selected as the meeting place for the fifteenth annual convention, March 20, 21, and 22, 1930.

Constitutional Amendments—The committee received the report of the ballot committee on amendments, composed of Richard Hughes, *chairman*, C. L. Severy, and Luther H. White, and declared the constititION amended as follows:

Art. IV, Sec. 5.—The officers shall assume the duties of their respective offices immediately after the annual meetings in which they are elected.

Art. VIII, Sec. 1 [amended by the addition of the following].—and such sections [regional and technical], with the approval of the executive committee, may admit as affiliated members of the sections persons who are not fully qualified for active or associate membership in the Association, subject to the re-

strictions provided for associate members in the constitution and such further restrictions as may be provided by the executive committee.

The first amendment carried by a vote of 845 to 37 and the second by a vote of 668 to 207. The entire constitution, as amended by this ballot (Art. IV and Art. VIII) and by vote of the fourteenth annual business meeting at Fort Worth (by-laws, Sec. 5 and Sec. 6), is printed in this *Bulletin*.

San Antonio District.—The committee announced the establishment of a new Association district, the San Antonio district, which will have the privilege of electing one representative on the general business committee which meets at each annual meeting of the Association.

Research Committee.—President Snyder announced the reappointment of the members of the research committee whose terms expired with last year's administration, and the appointment of one new member, R. D. Reed. The A. A. P. G. research committee is now composed of the following members (terms end with the annual meetings in March of the years shown in parentheses):

A. W. McCoy, *chairman* (1932)

Charles R. Fettke (1932)	M. K. Reed (1931)
A. I. Levorsen (1932)	F. B. Plummer (1931)
R. D. Reed (1932)	D. C. Barton (1930)
W. E. Wrather (1932)	R. C. Moore (1930)
K. C. Heald (1931)	W. T. Thom, Jr. (1930)
F. H. Lahee (1931)	F. M. Van Tuyl (1930)

CONSTITUTION AND BY-LAWS

(Adopted 1918 and amended 1921, 1923, 1925, 1927, 1928, and 1929)

Constitution

ARTICLE I. NAME

This Association shall be called the "American Association of Petroleum Geologists."

ARTICLE II. OBJECT

The object of this Association is to promote the science of geology, especially as it relates to petroleum and natural gas; to promote the technology of petroleum and natural gas and improvements in the methods of winning these materials from the earth; to foster the spirit of scientific research amongst its members; to disseminate facts relating to the geology and technology of petroleum and natural gas; to maintain a high standard of professional conduct on the part of its members; and to protect the public from the work of inadequately trained and unscrupulous men posing as petroleum geologists.

ARTICLE III. MEMBERS

SECTION 1. Any person actively engaged in the work of petroleum geology or in research pertaining to petroleum geology or technology is eligible to active membership in the American Association of Petroleum Geologists, provided he is a graduate of an institution of collegiate standing, in which institution he

has done his major work in geology, and in addition has had the equivalent of three years' field experience in petroleum geology; and provided further that in the case of an applicant for membership who has not had the required collegiate or university training, but whose standing in the profession is well recognized, he shall be admitted to membership when his application shall have been favorably and unanimously acted upon by the executive committee; and provided further that these requirements shall not be construed to exclude instructors and professors in recognized institutions of learning whose work is of such a character as in the opinion of the executive committee shall qualify them for membership.

The executive committee may grant life membership to active members who have paid their dues and are otherwise qualified.

SECTION 2. Any person having completed as much as thirty hours of geology (an hour shall here be interpreted as meaning as much as sixteen recitation or lecture periods of one hour each, or the equivalent in laboratory) in a reputable institution of collegiate or university standing, or who has done field work equivalent to this, shall be eligible to associate membership in the American Association of Petroleum Geologists, provided at the time of his application for membership he shall be engaged in geological studies in an institution of collegiate or university standing, or shall be engaged in geological work. The executive committee shall advance from associate to active membership those associates who have, subsequent to election, fulfilled the requirements for active membership without the formality of application for such change.

SECTION 3. Active and associate members shall be elected to the Association according to the qualifications outlined in Sections 1 and 2, provided that the applicant properly fills out the regular application blank, including the signature of *three* active members of the Association, and that such application be approved by at least three of the members of the executive committee of the Association, as provided for in Article IV, Sections 1 and 4.

SECTION 4. Associate members shall enjoy all privileges of membership in the Association, save that they shall not hold office, sign applications for membership, or vote in business meetings; neither shall they have the privilege of advertising their associate membership in the Association in professional cards, nor shall they have the privilege of signing professional reports as associate members of the Association.

SECTION 5. Each applicant for membership shall formally be notified in writing by the secretary of his election, and shall be furnished with a membership card for the current year, and until such formal notice and card are received, he shall in no way be considered a member of the Association.

SECTION 6. Applications for membership may be accepted at any time, but unless an applicant shall have his application approved and have been formally notified by the secretary of his election at least one month before the annual meeting, he shall not be allowed to participate in the business of said annual meeting.

SECTION 7. The executive committee may from time to time elect as honorary members persons who have contributed distinguished service to the cause of petroleum geology. Honorary members shall not be required to pay dues, nor shall they be allowed to vote.

ARTICLE IV. OFFICERS

SECTION 1. The officers of the Association shall consist of a president, a first vice-president, a second vice-president in charge of finances, and a third vice-president in charge of editorial work. These, together with the retiring president, shall constitute the executive committee and managers of the Association.

SECTION 2. The officers shall be elected annually from the Association at large by written ballot deposited in a locked ballot box by those active members present at the annual meeting, who have paid their current dues and are otherwise qualified under the constitution.

SECTION 3. No man shall hold the office of president or vice-president for more than two years in succession.

SECTION 4. The executive committee shall consider all nominations for membership and pass on the qualifications of the applicant; shall have the control of the Association's work and property; shall determine the manner of publication, and pass on all materials presented for publication; and may call special meetings when and where thought advisable, and arrange for the affairs of the same.

SECTION 5. The officers shall assume the duties of their respective offices immediately after the annual meetings in which they are elected.

SECTION 6. The fiscal year of the Association shall correspond with the calendar year.

ARTICLE V. MEETINGS

The annual meetings shall be held at a time most convenient for the majority of the members at a place designated by the executive committee. At this meeting the election of members shall be announced, the proceedings of the preceding meeting be read, all Association business transacted, scientific papers read and discussed, and officers for the ensuing year shall be elected.

ARTICLE VI. AMENDMENTS

This constitution may be amended at any time, provided that such amendment is proposed and signed by at least five members of the Association, and is presented and discussed at any annual meeting of the Association. The secretary shall take a ballot of the membership by mail within thirty days after the meeting of the Association, and a majority vote of the ballots received shall be sufficient to amend, provided more than one-half of the members return ballots.

ARTICLE VII. PUBLICATION

The proceedings of the annual meeting and the papers read shall be published in the annual bulletin. This shall be under the immediate supervision of the vice-president in charge of editorial work, assisted by associate editors whom he shall appoint in the various regions.

ARTICLE VIII. SECTIONS

SECTION 1. Regional and technical sections of the Association may be established, provided the members of such sections shall perfect an organization and make application to the executive committee, who shall submit the application to a vote at a regular annual meeting, a vote of two-thirds of the mem-

bers present being necessary for the establishment of such a section; and provided that the Association may revoke the charter of any section by a vote of two-thirds of the membership; and such sections, with the approval of the executive committee, may admit as affiliated members of the sections persons who are not fully qualified for active or associate membership in the Association, subject to the restrictions provided for associate members in the constitution and such further restrictions as may be provided by the executive committee.

BY-LAWS

SECTION 1. *Dues.*—The regular annual dues of an active member of the Association shall be $15.00. The annual dues of an associate member of the Association shall be $10.00. The annual dues are to be paid to the Association on or about January first for the year ending the following December.

The fee required for life membership shall be $300 payable in advance. Life membership fees shall become a permanent investment, the income from which shall be devoted to the same purposes as the regular dues.

SECTION 2. Any member who shall fail to pay his regular annual dues for a period of one year may be dropped from membership by a vote of the executive committee, but may later apply for membership under the regular rules, if desired.

SECTION 3. The payment of annual dues entitles the member to receive, without further charge, one copy of the proceedings of the Association for that year.

SECTION 4. Any member who shall be guilty of flagrant violation of the established principles of professional ethics may, upon the unanimous vote of the executive committee, be suspended or expelled from membership, provided that such person shall before suspension or expulsion be granted a hearing before the executive committee.

SECTION 5. The executive committee shall from time to time designate and define districts and shall determine, according to the number of active members residing in each such district, the number of representatives to which it is entitled, and the active members in each such district shall choose, in such manner as to them seems best, the number of representatives to which the district is entitled. The terms of all district representatives hereafter elected shall be two years, and shall expire at the same time as the terms of officers.

SECTION 6. There shall be a business committee to act as a council and advisory board to the executive committee and the Association. This committee shall be made up of the executive committee, not more than five members at large appointed by the president, two members elected by and from each technical section, and the district representatives. The president shall also appoint a chairman from within or without the number of those theretofore chosen for the committee. If a district or technical representative is unable to be present at any meeting of the committee he may designate an alternate, who, in the case of a district representative, may or may not be a resident of the district he is asked to represent, and the alternate, on presentation of such a designation in writing, shall have the same powers and privileges as a regularly chosen representative.

AMENDMENTS

These by-laws may be amended by a vote of three-fourths of the active members present at any annual meeting.

NATIONAL RESEARCH COUNCIL

The National Research Council was established in 1916 during the World War by the National Academy of Sciences at the direction of the President of the United States for the purpose of advising the Government regarding scientific matters. It is a voluntary organization dependent for financial support wholly upon private donations. It is housed with the Academy in a beautiful new building at the corner of B and 21st Streets, Washington.

The work of the National Research Council is conducted through divisions, of which the division of Geology and Geography is one. The division chairmen are elected for a period of one year by the members of the division and receive a salary from the Council. The members are the chairman, vice-chairman, elective members-at-large, and representatives of scientific societies.

The Division now embraces 28 members, of whom 17 were nominated by and represent 8 geological or geographical scieties; 9 are members-at-large, and 2 represent other divisions or were appointed for special purposes. Members serve for three years, and, after completing term of office in one capacity, may serve in another capacity. For example, a representative of the Association might serve a 3-year appointment on the Division, and then might serve an additional 3-year appointment as a member-at-large. (W. E. Wrather did this.)

The research work of the Division is conducted by technical committees, the chairmen and members of which are not necessarily members of the division. At present there are 25 committees. Those whose work is of special interest to the members of this Association are on micro-paleontology, sedimentation, bibliography of economic geology, isostasy, tectonics, conservation of the scientific results of drilling, and studies in petroleum geology.

Annual meetings of the Division of Geology and Geography are held in April, and a report is presented from each committee. Similar statements are desirable from representative members of constituent societies in regard to the outstanding research work in their organizations. At the meeting held April 27, 1929, a report was made of the research work of this Association by one of its representatives (Sidney Powers).

Announcements of work by committees of the Division of interest to this Association were as follows:

Coöperation by the Committee on Micro-Paleontology under the chairmanship of J. A. Cushman, Sharon, Massachusetts, in assisting micro-paleontologists in the identification and descriptions of micro-fossils.

Preparation was announced of a revision of the *Treatise on Sedimentation* by W. H. Twenhofel, University of Wisconsin, Madison, Wisconsin, chairman of the Committee on Sedimentation. The income from the sale of this book is used by the committee to further research. Criticisms of the first edition and suggestions concerning additions to the second edition will be welcomed by Professor Twenhofel at once.

The first volume of the *Bibliography of Economic Geology*, made available through the indefatigable efforts of Waldemar Lindgren, Massachusetts Institute of Technology, Cambridge, Massachusetts, is in the publisher's hands, and is expected to appear early in the summer. Subscriptions are $5.00 per year and should be sent to Professor W. S. Bayley, business manager, Economic

Geology Publishing Company, Urbana, Illinois. The first volume covers the literature for 1928, and it is expected that thereafter there will be two volumes per year.

A tectonic map of the United States is being prepared under the direction of the Committee on Tectonics, G. R. Mansfield, chairman, U. S. Geological Survey. Contributions of surface and subsurface geological maps (with or without structure contours) showing axes of folding, location of domes, and lines of faulting over large areas will be greatly appreciated by him. Unpublished data from petroleum geologists are essential to the compilation of much of this map, and these data will be considered as confidential by Dr. Mansfield for any period of time specified by the donor. A preliminary general map will be issued as soon as the information in hand justifies it. Within the limits of the scale the map will show domes, axes of folds, and normal and overthrust faults. More detailed maps of regions of intense oil development will classify these features according as they are exposed at the surface, found by drilling, or inferred from drilling.

Laws of Crustal Deformation is the title of a book being prepared by W. H. Bucher, University of Cincinnati, Ohio, a member of the Committee on Tectonics.

Studies in petroleum geology are not being made by the Division committee, *per se*, but through the Central Petroleum Committee, which is a Committee of the Executive Board of the Research Council appointed to coöperate with the American Petroleum Institute in recommending desirable projects to be undertaken by the Institute as part of its program of scientific research in the geology, physics, and chemistry of petroleum, made possible through funds from John D. Rockefeller, Sr., and the Universal Oil Products Company of Chicago. The 38 or more projects in petroleum research being carried on under the auspices of the American Petroleum Institute are described in the Bulletins of the Institute for March 31, May 4, August 24, and September 21, 1927, and September 7, 1928. K. C. Heald, E. L. DeGolyer, and David White serve as the representatives of the Division on the Central Petroleum Committee.

A list of areal geological maps of each state has been compiled by members of the U. S. Geological Survey and is given as Appendix S, Exhibit A, of the report of the Committee on Tectonics which can be secured from the National Research Council.

A set of maps of Hispanic America on the millionth scale is being compiled and printed by the American Geographical Society, of New York City.

The Second International Drilling Congress will meet in Paris, September, 1929, and problems of technique of drilling and conservation of cuttings and logs will be considered.

Arthur Keith, on leave of absence from the U. S. Geological Survey, was re-elected chairman of the Division for the year beginning July 1, 1929.

SIDNEY POWERS, Representative, 1928-30.
ALEX W. MCCOY, Representative, 1929-31.
Members of National Research Council, Division of Geology and Geography.

AT HOME AND ABROAD

The SIXTH INTERNATIONAL PETROLEUM EXPOSITION is to be held at Tulsa, Oklahoma, October 5-12, inclusive.

C. D. JOHNSON, petroleum geologist, and C. E. SHOENFELT, petroleum engineer, have announced the incorporation of Petroleum Information, Inc., with offices in the Continental Oil Building, Denver, Colorado.

W. T. GALLAGHER, chief geologist, and C. E. MANION, geologist, for the Union Oil Company at Fort Collins, Colorado, have been transferred to Abilene, Texas.

J. H. VAN ZANT, formerly of the Healdton Oil & Gas Company at Enid, has joined the geological staff of the Wrightsman Petroleum Corporation at Tulsa, Oklahoma.

PAUL B. HUNTER resigned from the Marland Production Company last February to accept a position with the Shell Petroleum Corporation. Mr. Hunter has charge of geological work for the corporation in Michigan, with headquarters at Muskegon.

J. M. SANDS, consulting geologist for Phillips Petroleum Company at Bartlesville, Oklahoma, has been made a vice-president of that company.

WILLIAM M. MCGILL is assistant state geologist, Virginia Geological Survey, University of Virginia.

T. C. THOMPSON, consulting geologist, is associated with JACK E. KELLY at Vernon, Texas. Activities for the coming year will be confined to the Waggoner pasture.

BAILEY WILLIS, emeritus professor of geology at Stanford University and research associate in seismology of the Carnegie Institution of Washington, is studying earthquakes in East Africa.

FREDERICK G. CLAPP, consulting geologist, 50 Church Street, New York City, is the author of a series of articles about his experiences while working for the Persian Government. His second article is in the *Oil and Gas Journal* for April 18, 1929. Mr. Clapp has been in Paris most of the past winter. In February and March he visited the oil fields of the Red Sea.

G. GORDON THOMAS, London representative in South West Africa for the Whitworth Finance and Mining Corporation, Limited, returned to London this month.

The San Antonio Geological Society has been chartered by the A. A. P. G. as a regional section of the Association. This is the second section of the A. A. P. G., the first being the Pacific Section. Officers of the San Antonio Section are: CHARLES H. ROW, Sun Oil Company, president; R. F. SCHOOLFIELD,

Rosito Oil Company, vice-president; KENNETH DALE OWEN, Southern Crude Oil Purchasing Company, Frost National Bank Building, secretary-treasurer.

W. F. CHISHOLM, supervisor of the minerals division of the Louisiana Conservation Department at Shreveport, was selected by the southern division of the American Mining Congress to represent the state at the fourth annual Industrial Development Conference at Atlanta, Georgia.

S. L. GILLAN, mining engineer and geologist associated with RALPH ARNOLD, VAN COURT WARREN, and WAYNE LOEL, has moved his office from the Stock Exchange Building to 812 Subway Terminal Building, Los Angeles, California.

ARTHUR KNAPP has an article on "Larger Operating Units Are Needed to Check Overproduction," in *Oil Field Engineering* for May 1, 1929.

RICHARD A. JONES is the author of an article on "Black Diamonds" in the *Oil Weekly* for April 26, 1929.

HALL EDWARDS is in charge of the Sun Royalty Company, a division of the Sunray Oil Company, Exchange National Bank Building, Tulsa, Oklahoma.

ERNEST R. LILLEY writes on "Relationship of Government and Oil" in the *Oil and Gas Journal* of April 25, 1929.

LESTER C. UREN has a paper on "Inert Gas Provides Security Against Fire in Concrete Oil Reservoirs," in *National Petroleum News* of April 24, 1929.

HOYT S. GALE is chief geologist of the Western Gulf Oil Company (formerly Pacific Eastern Production Company).

R. G. REESE, formerly of the Associated Oil Company, is on the geological staff of the Standard Oil Company of California.

Official representatives of the A. A. P. G. to several world-wide scientific conferences this year are as follows: Fourth Pacific Science Congress, Batavia and Bandoeng, Java, May 16-25, A. C. LAWSON and GEORGE D. LOUDERBACK; Fifteenth International Geological Congress, Pretoria, South Africa, July 29-August 7, JAMES A. MACDONELL, JOSEPH T. SINGEWALD, JR., and W. E. WRATHER; World Engineering Congress, Tokio, Japan, October 30-November 20, E. L. DEGOLYER, F. O. MARTIN, TSUNENAKA IKI, GIICHIRO KOBAYASHI, B. KOTO, and RAPHAEL J. TAKAHASHI.

F. C. SEALEY, formerly chief geologist for The Texas Company in northern Texas, is now assistant to the general manager of production in the Gulf Coast division, at Houston, Texas.

W. W. SCOTT, petroleum engineer, Humble Oil and Refining Company, Houston, Texas, read a paper on "Modern Methods of Deep Well Drilling," at the meeting of the American Society of Civil Engineers held at Dallas, April 24 and 25. The paper appeared in the *Oil Weekly* of May 3, 1929.

H. W. BELL, formerly with The Pure Oil Company, is production engineer for the Lion Oil and Refining Company at Wink, Texas.

President J. Y. SNYDER and past-president R. S. McFARLAND of the A. A. P. G., presented before the Tulsa Geological Society, May 6, 1929, the importance of continued and increased funds for the operation of the U. S. Geological Survey.

H. E. CRUM has accepted the position of district geologist for the Skelly Oil Company in charge of the Panhandle district with headquarters at Amarillo, Texas. Mr. Crum was formerly associated with Fisher and Lowrie of Denver, Colorado, but for the past seven years has been operating independently in Colorado, Kansas, and Texas.

E. V. WHITWELL, formerly with the Marland Oil Company, represents the Carter Oil Company at Meridian, Mississippi.

D. R. SEMMES has written a bulletin on oil and gas in Alabama which will be issued by the Alabama Geological Survey. Mr. Semmes has headquarters in New York City at 25 Broadway, care E. B. Hopkins.

RAYMOND C. MOORE, director of the Kansas Geological Survey, announces the project of a new areal map of the state, field work on which is in progress.

ION POPESCU VOITESTI, of Cluj, Roumania, wrote the foreword to the treatise on the geology of Persia, reviewed in the April number of this *Bulletin*.

C. O. DUNBAR, of Yale University, is author of *Bulletin 2* of the Nebraska Geological Survey, "The Fusulinidae of the Pennsylvanian System in Nebraska."

R. S. BASSLER, curator of stratigraphic paleontology in the U. S. National Museum, is spending the summer in Czecho-Slovakia.

ARTHUR BEVAN, assistant professor of geology at the University of Illinois, has been appointed state geologist of Virginia.

CHARLES LAURENCE BAKER, of Houston, Texas, published "Desert Range Tectonics of Trans-Pecos Texas and New Mexico" in the *Pan-American Geologist*, Vol. 50, December, 1928.

MAX W. BALL, president of the Milmac Oil Company, has headquarters in the Exchange National Bank Building, Tulsa.

SAMUEL W. WELLS has resigned from the Shell Petroleum Corporation to engage in the oil business for himself at Okmulgee, Oklahoma.

E. O. TEALE, director, Geological Survey of Tanganyika, published a map of the geology known to date in the *Annual Report for 1927*, Tanganyika Territory, Dodoma, Africa.

W. C. SPOONER'S report on the geology and oil fields of the Coastal Plain sediments of Arkansas will be published this summer by the Arkansas Geological Survey.

DOUGLAS W. JOHNSON, of Columbia University, is attending the International Geological Congress at Pretoria, South Africa, on a trip around the world.

WILLIAM J. MILLARD, consulting geologist, who has been examining the Orinoco delta of Venezuela for The Texas Company, is planning to spend the summer in New York.

CHESTER A. BAIRD, subsurface geologist for the Venezuelan Gulf Oil Company at Maracaibo, Venezuela, spent his vacation in the United States.

R. VAN A. MILLS has resigned from the *Oil and Gas Journal*, to become vice-president and general manager of the Marland-Hudson Bay Oil Company, with headquarters at Edmonton, Alta., Canada.

LLOYD NORTH has resigned from The Texas Company to enter the oil business for himself at Sequin, Texas.

The annual field trip of the Shreveport Geological Society, June 7, 8, and 9, was conducted by bus from Memphis, visiting Columbia, Tennessee, Muscle Shoals, Alabama, and Tupelo, Mississippi. The Eocene, Cretaceous, and Paleozoic sections were studied.

PHILIP B. KING is spending the summer in the Marathon district, working for the U. S. Geological Survey on the areal map of Texas which is being compiled by the Survey with the coöperation of the Bureau of Economic Geology, Austin, and the A. A. P. G.

The geologists stationed in the Shawnee and Seminole areas have recently completed the organization of a geological society to be known as the Shawnee Geological Society. The regular meetings of the society will be held on the fourth Monday of each month at 6:30 P. M. at which a dinner will be served followed by a technical session. The officers of the society are as follows: president, JESS VERNON, Amerada Oil Company; vice-president, OSCAR HATCHER, Gypsy Oil Company; secretary-treasurer, H. H. KISTER, Dixie Oil Company.

The San Antonio Section of the A. A. P. G. holds informal luncheons on the second, third, and fourth Mondays of each month, in the private dining room of the San Antonio Petroleum Club, second floor of the Milam Building. The first Monday evening of each month is set aside for a dinner and technical session.

KURT DE COUSSÈR, formerly with the Transcontinental Oil Company, accepted a position with the Prairie Oil and Gas Company at Tulsa, effective May 1, 1929.

B. K. N. WYLLIE, of the Anglo-Persian Oil Company, London, left last May to take charge of the geological survey work in Papua which his company is conducting in behalf of the Commonwealth Government. His address is 485 Bourke Street, Melbourne, Australia.

PROFESSIONAL DIRECTORY

SPACE FOR PROFESSIONAL CARDS IS RESERVED FOR ACTIVE MEMBERS OF THE ASSOCIATION. FOR RATES, APPLY TO THE BUSINESS MANAGER, BOX 1852, TULSA, OKLAHOMA

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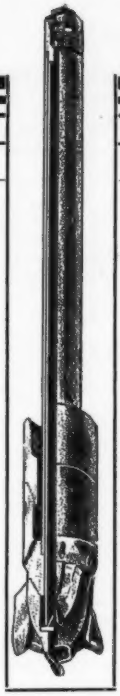

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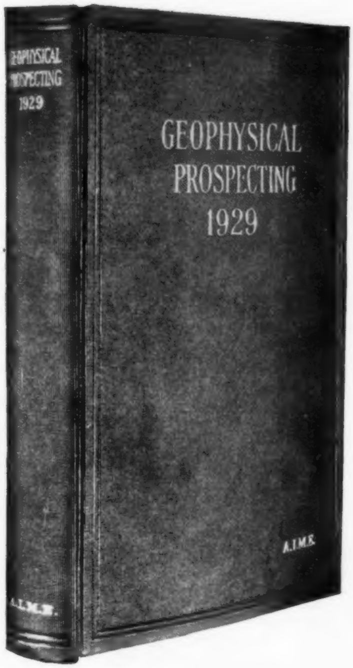

The first collection of papers presented by the A. I. M. E. Committee on Geophysical Prospecting.

The papers in this special volume were presented at the New York, 1928, and Boston, 1928, meetings. A few address the specialist; others afford mining men an insight into the economic value of particular methods. Two are general in application; nine treat of electrical, seven of magnetic, six of gravity, and three of seismic methods.

A copy of this book has been mailed to all members of the A. I. M. E. who have requested the Geophysical Prospecting papers. Other members may have a copy on request without charge.

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